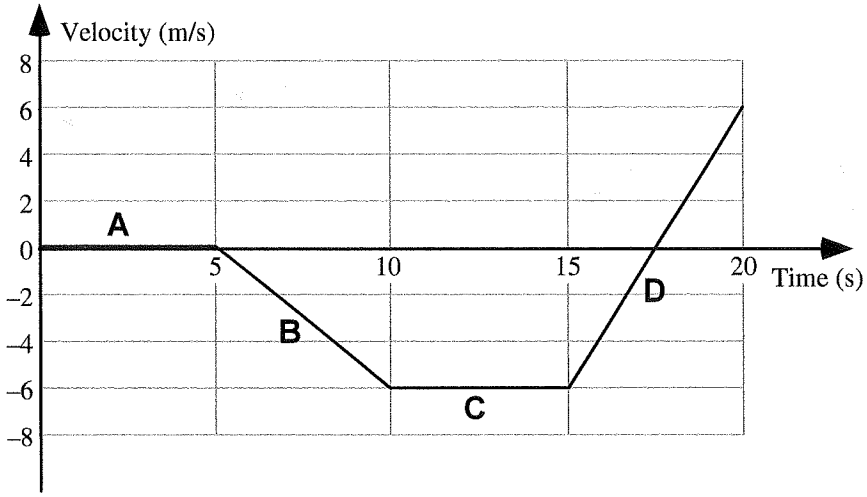
B4-RT10: VELOCITY-TIME GRAPH II—WORK DONE ON BOX

Shown below is a graph of velocity versus time for an object that moves along a straight, horizontal line under the perhaps intermittent action of a single force exerted by an external agent.



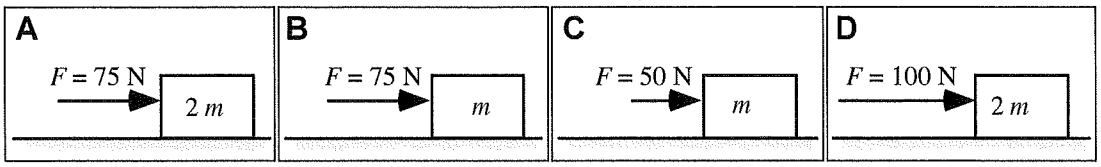
Rank the work done on the box by the external agent for the 5-second intervals shown on the graph.

				OR		
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B4-RT11: FORCE PUSHING BOX—CHANGE IN KINETIC ENERGY

A box is pushed 10 m across a floor in each case shown. All boxes have an initial velocity of 10 m/s to the right. The mass of the box and the net horizontal force for each case are given.



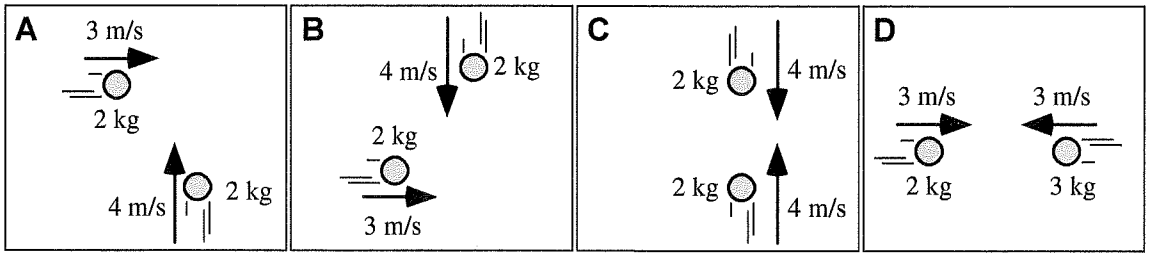
Rank the change in kinetic energy of the boxes.

				OR		
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B4-QRT12: Two Ball Systems—Kinetic Energy of System

In the figures below, systems of two balls are traveling in different directions. The balls are identical in size and shape, but they have different masses and are traveling at different velocities as shown.



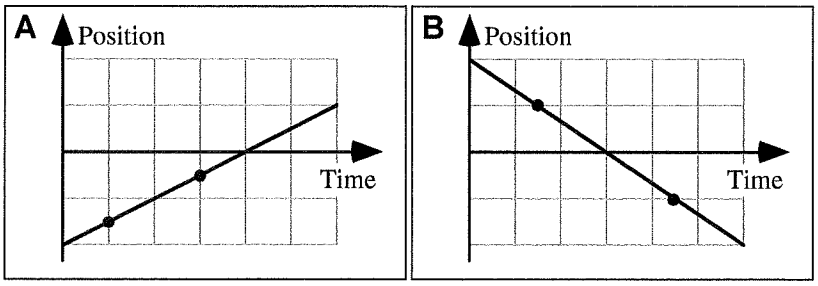
Rank the total kinetic energy of the two-ball systems before they interact.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B4-WWT13: Boat Position-Time Graphs—Work

Shown are graphs of the position versus time for two boats traveling along a narrow channel. The scales on both axes are the same for the graphs. In each graph, two points are marked with dots.



A student who is using these graphs to compare the net work done on the two boats between the two points says:

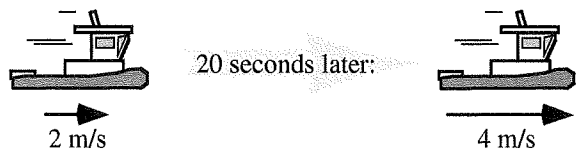
"I think that more net work was done on the boat in graph B because it moved farther during the interval between the points."

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

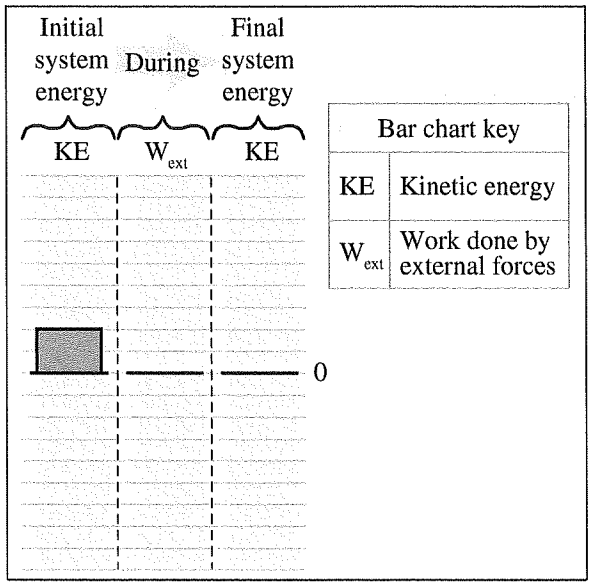
B4-BCT14: TUGBOAT CHANGING VELOCITY I—WORK & KINETIC ENERGY BAR CHART

(a) The velocity of a tugboat increases from 2 m/s to 4 m/s in the same direction while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

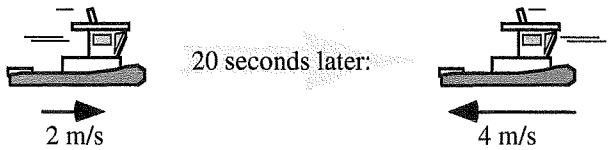


Explain.

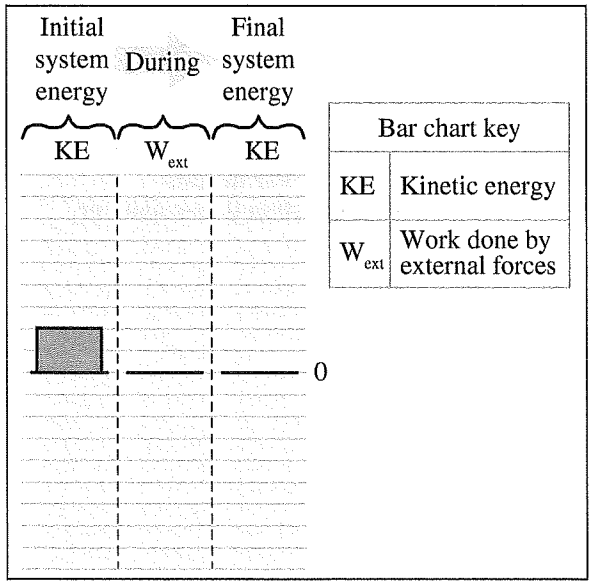


(b) The velocity of a tugboat changes from 2 m/s to 4 m/s in the opposite direction while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.



Explain.

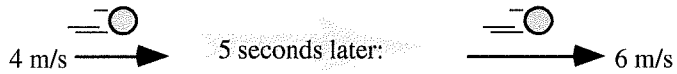


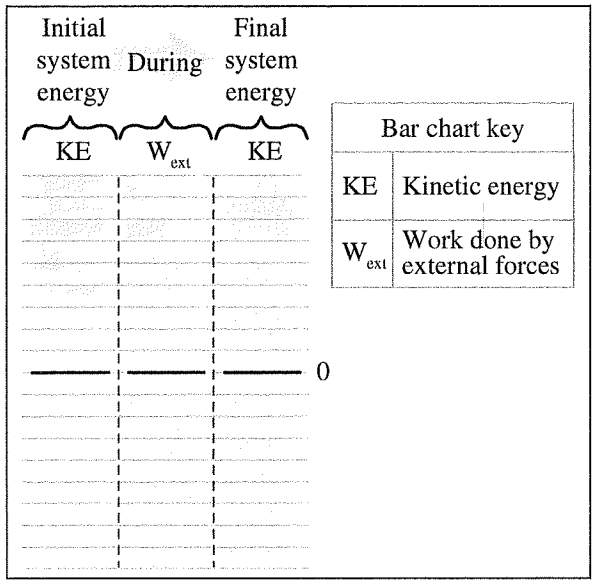
B4-BCT15: Object Changing Velocity I—Work and Kinetic Bar Chart

A 2-kg object changes its velocity as a force acts on it for 5 seconds. It changes its velocity from 4 m/s east to 6 m/s east as shown.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

Explain your reasoning.



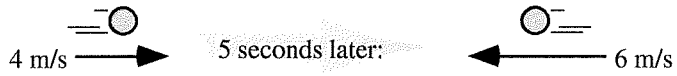


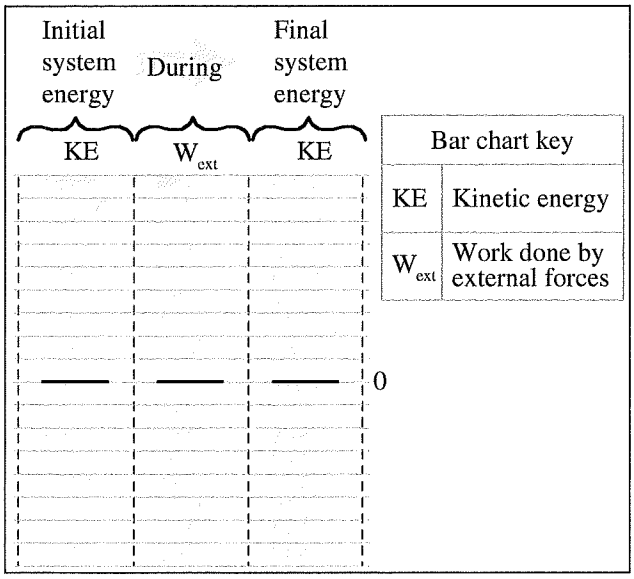
B4-BCT16: Object Changing Velocity II—Work and Kinetic Bar Chart

A 2-kg object changes its velocity as a force acts on it for 5 seconds. It changes its velocity from 4 m/s east to 6 m/s west as shown.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

Explain your reasoning.

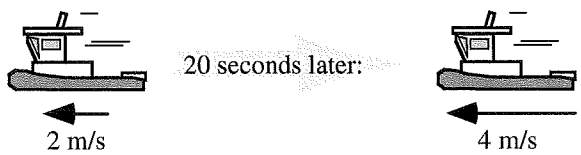




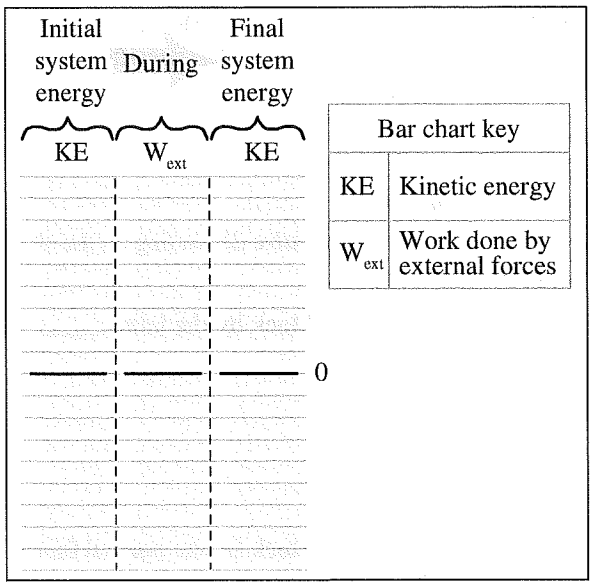
B4-BCT17: TUGBOAT CHANGING VELOCITY II—WORK AND KINETIC ENERGY BAR CHART

(a) The velocity of a tugboat changes from 2 m/s west to 4 m/s west while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

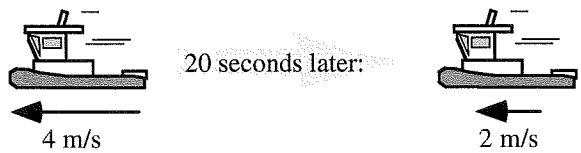


Explain.

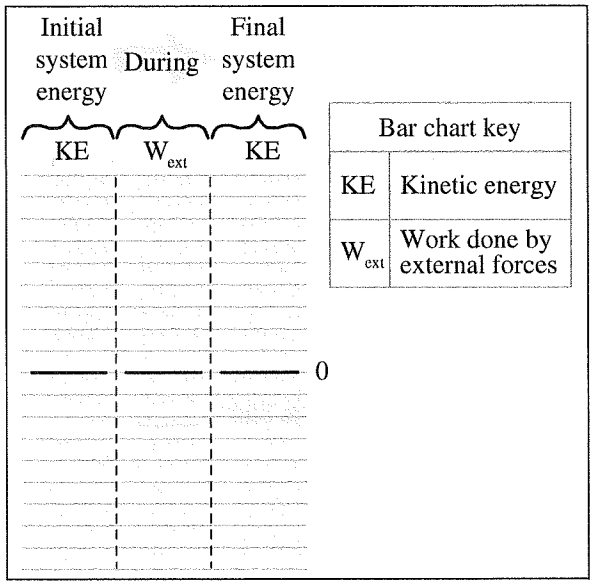


(b) The velocity of a tugboat changes from 4 m/s west to 2 m/s west while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

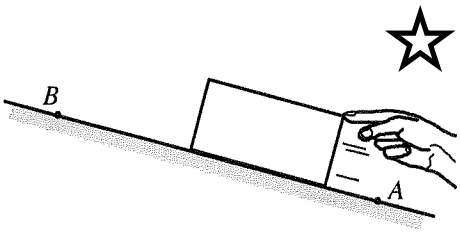


Explain.



B4-LMCT18: Block Pushed on Incline—Work Done

A block is pushed so that it moves up a ramp at constant speed.



Identify from choices (i)–(iv) below the appropriate description for the work done by the specified force while the block moves from point *A* to point *B*.

(i) is *zero.*
(ii) is ***less than*** zero.
(iii) is ***greater than*** zero.
(iv) could be ***positive or negative*** depending on the choice of coordinate systems.
(v) ***cannot*** *be determined.*

(a) The work done on the block by the hand. _____
Explain your reasoning.

(b) The work done on the block by the normal force from the ramp. _____
Explain your reasoning.

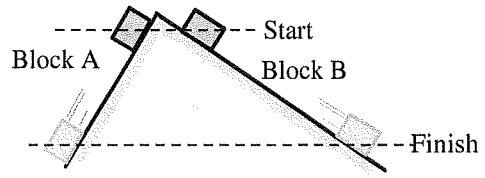
(c) The work done on the block by friction. _____
Explain your reasoning.

(d) The work done on the block by the gravitational force. _____
Explain your reasoning.

(e) The net work done on the block. _____
Explain your reasoning.

B4-SCT19: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK BY THE NORMAL FORCE

Two identical blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Three students are comparing the work done on the two blocks by the normal force:



Annika: *"I think the normal force doesn't do any work on either block. The force on the block by the ramp is perpendicular to the ramp, and the displacement is parallel to the ramp. So the dot product is zero."*

BoBae: *"Work is force times displacement. The work done on Block A is negative, while the work done on Block B is positive, because the displacement for B is in the positive direction, while the displacement for A is in the negative direction."*

Craig: *"Since work is force times distance, and the distance the block travels is greater for Block B, the work done is greater for Block B."*

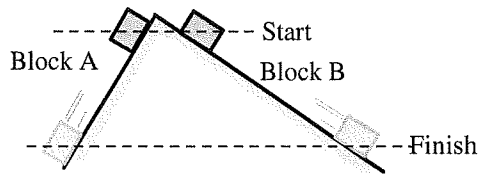
With which, if any, of these students do you agree?

Annika _____ BoBae _____ Craig _____ None of them_____

Explain your reasoning.

B4-SCT20: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK BY THE EARTH

Two identical blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Three students are comparing the work done on the two blocks by the gravitational force (the weight of the blocks):



Asmita: *"Work is related to the product of force and displacement, and the weight is the same since the blocks are identical. But Block B travels farther, so more work is done on Block B by the gravitational force than on Block A."*

Ben: *"Both blocks fall the same vertical distance, so the work done is the same."*

Cocheta: *"By Newton's third law, the force exerted on the block by Earth is exactly cancelled by the force exerted on Earth by the block. The work done is zero."*

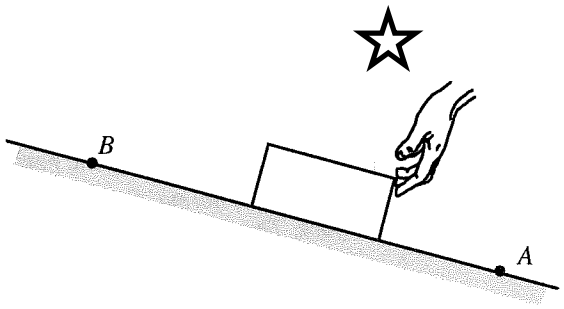
Danae: *"The work depends on the angle that the force makes with the displacement. If we put the displacement and force vectors tail-to-tail, the angle is smaller for Block B than for Block A, and so the work done is greater."*

With which, if any, of these students do you agree?

Asmita _____ Ben _____ Cocheta _____ Danae _____ None of them_____

Explain your reasoning.

B4-QRT21: Block on Ramp with Friction—Work



A block is pushed at constant speed up a ramp from point *A* to point *B*. The direction of the force on the block by the hand is horizontal. There is friction between the block and the ramp. The distance between points *A* and *B* is 1 m.

(a) The work done on the block by the hand as the block travels from point *A* to point *B*

(i) is *zero.*
(ii) is *negative.*
(iii) is *positive.*
(iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

(b) The work done on the block by the normal force from the ramp as the block travels from point *A* to point *B*

(i) is *zero.*
(ii) is *negative.*
(iii) is *positive.*
(iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

(c) The work done on the block by the friction force from the ramp as the block travels from point *A* to point *B*

(i) is *zero.*
(ii) is *negative.*
(iii) is *positive.*
(iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

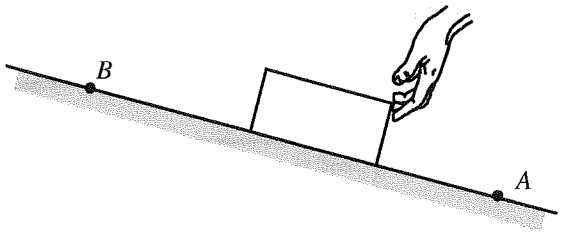
(d) The work done on the block by the gravitational force of the earth as the block travels from point *A* to point *B*

(i) is *zero.*
(ii) is *negative.*
(iii) is *positive.*
(iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

B4-QRT22: BLOCK ON RAMP WITH FRICTION—WORK AND ENERGY

A block is pushed at constant speed up a ramp from point A to point B. The direction of the force on the block by the hand is horizontal. There is friction between the block and the ramp. The distance between points A and B is 1 m.



(a) The kinetic energy of the block at point B

(i) is *greater than* the kinetic energy of the block at point A.
(ii) is *less than* the kinetic energy of the block at point A.
(iii) is *equal to* the kinetic energy of the block at point A.
(iv) *cannot be compared* to the kinetic energy of the block at point A unless we know the height difference between A and B.

Explain your reasoning.

(b) The net work done on the block as it travels from point A to point B

(i) is *zero*.
(ii) is *negative*.
(iii) is *positive*.
(iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

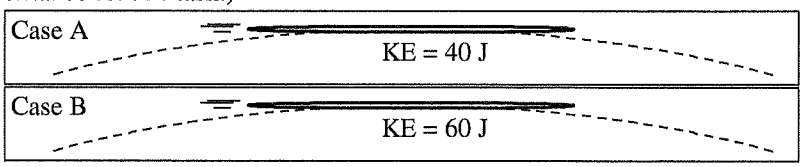
(c) The work done on the block by the hand as the block travels from point A to point B

(i) is *equal* to 1 m times the magnitude of the force exerted on the block by the hand.
(ii) is *greater than* 1 m times the magnitude of the force exerted on the block by the hand.
(iii) is *less than* 1 m times the magnitude of the force exerted on the block by the hand but not zero.
(iv) is *zero*.
(v) *cannot be compared* to the magnitude of the force exerted on the block by the hand based on the information given.

Explain your reasoning.

B4-CT23: Thrown Javelins—Horizontal Force

Shown are two javelins (light spears) that have been thrown at targets. We are viewing the javelins when they are in the air about halfway to landing. Both javelins have the same mass, but they have different kinetic energies as shown. (Ignore air resistance for this task.)



Is the horizontal force acting on the javelin in Case A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the horizontal force acting on the javelin in Case B? _____

Explain your reasoning.

B4-SCT24: Skaters Pushing off Each Other—Force

Two skaters—a small girl and a large boy—are initially standing face-to-face but then push off each other. After they are no longer touching, the girl has more kinetic energy than the boy. Three physics students make the following contentions about the forces the boy and girl exerted on each other:

Arianna: *"I think the boy pushed harder on the girl because he is bigger, so she ended up with more kinetic energy than he did."*

Boris: *"I disagree. They pushed equally hard on each other, but the girl moved farther while they were pushing on each other, so she ended up with more kinetic energy."*

Carmen: *"I think the girl had to push harder to get the boy moving since he is bigger, but that caused her to accelerate more as she recoiled."*

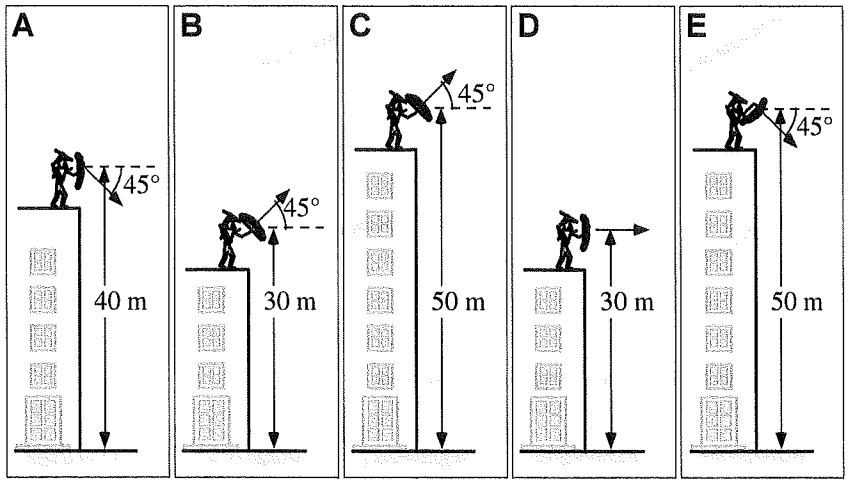
With which, if any, of these students do you agree?

Arianna _____ Boris _____ Carmen _____ None of them_____

Explain your reasoning.

B4-RT25: ARROWS SHOT FROM BUILDINGS—FINAL SPEED

In each case below, an arrow has been shot from the top of a building either up at a 45° angle, straight out horizontally, or down at a 45° angle. All arrows are identical and are shot at the same speed, and the heights of the buildings and the direction the arrows are shot are given. Ignore air resistance.



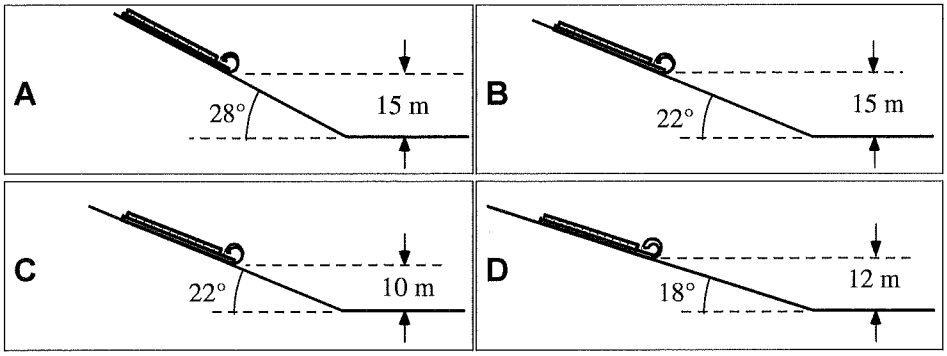
Rank the speed of the arrows just before they hit the ground below.

					OR			
						☐	☐	☐
1 Greatest	2	3	4	5 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B4-RT26: Toboggans Going Down Slippery Hills—Speed at Bottom

In each case below, a toboggan starts from rest and slides without friction down a snowy hill. The toboggans are all identical, and the starting heights (vertical distance above the flat bottom of the incline) and angles of the hills are given.



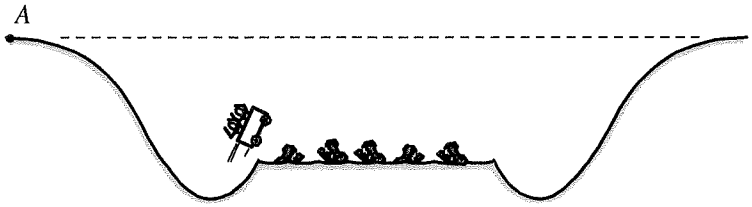
Rank the speed of the toboggans at the bottom of the incline.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B4-CT27: Roller Coaster Ride over Lagoon—Maximum Height

For extra excitement, a new roller coaster ride is designed to launch the riders over an alligator-infested lagoon. The frictionless coaster starts at rest at point *A*. The coaster lands on a ramp on the other side of the lagoon.

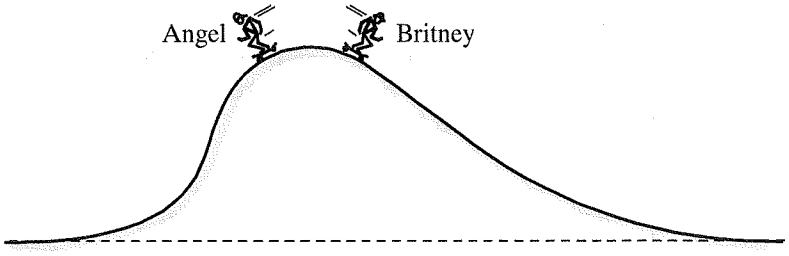


After it is airborne, will the maximum height of the coaster be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the height at point *A*? _____

Explain your reasoning.

B4-CT28: SKATEBOARDERS ON A HILL—TIME, SPEED, KINETIC ENERGY, AND WORK

Starting from rest, Angel and Britney skateboard down a hill as shown. Angel rides down the steep side while Britney rides down the shallow side. Angel has more mass than Britney. Assume that friction and air resistance are negligible.



(a) Is the speed at the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

(b) Is the time it takes to get to the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

(c) Is the work done by the gravitational force on the skateboarder (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

(d) Is the work done by the normal force on the skateboarder (i) *greater* for Angel, (ii) greater for Britney, or (iii) *the same* for both skateboarders? _____

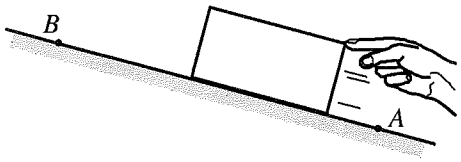
Explain your reasoning.

(e) Is the kinetic energy at the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

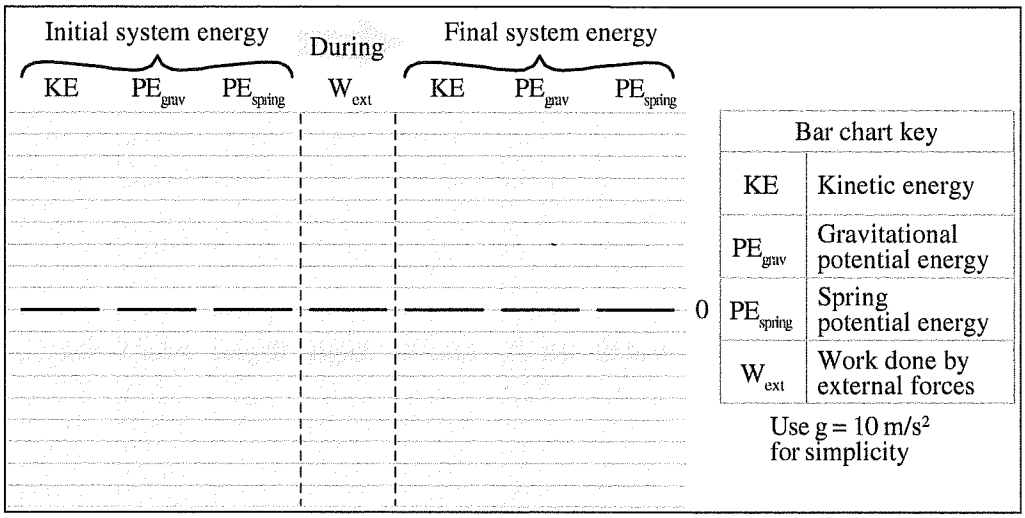
Explain your reasoning.

B4-BCT29: Block Pushed on Smooth Ramp—Energy Bar Chart

A block is pushed so that it moves up a smooth (frictionless) ramp at constant speed from *A* to *B*.



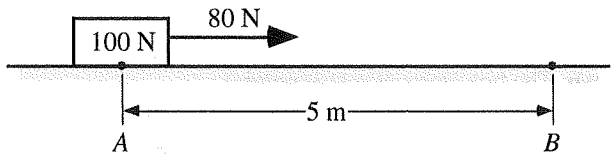
Complete the energy bar chart for the earth-block system as the block moves from point *A* to *B*. Put the zero point for the gravitational potential energy at *A*.



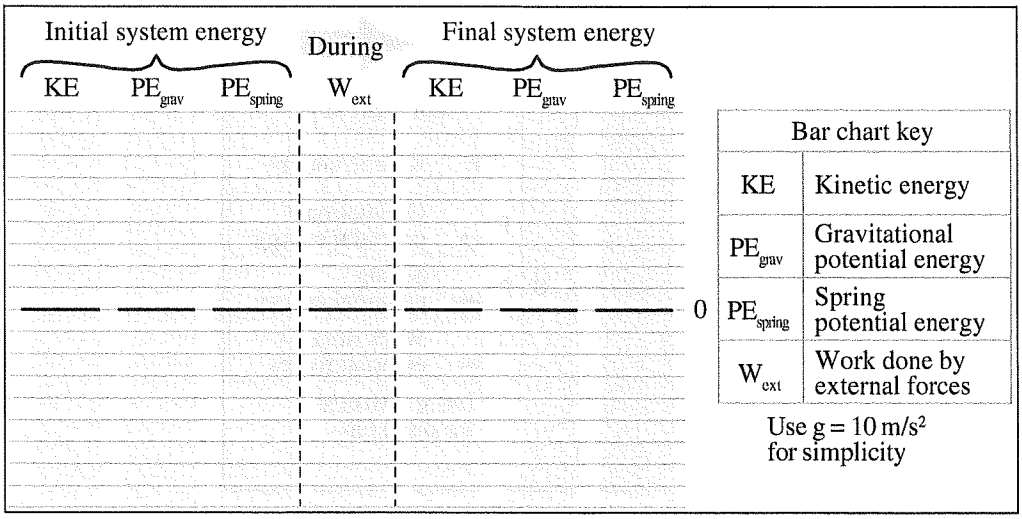
Explain your reasoning.

B4-BCT30: BOX PULLED ON SMOOTH SURFACE—ENERGY BAR CHART

A 100-N box is initially at rest at point *A* on a smooth (frictionless) horizontal surface. A student applies a horizontal force of 80 N to the right on the box as shown.



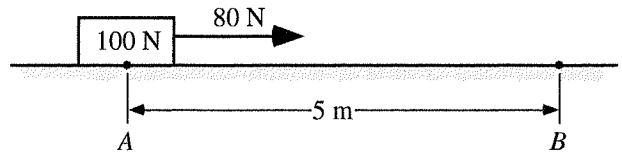
Complete the energy bar chart for the earth-box system before and after the box has moved a horizontal distance of 5.0 m. Put the zero point for the gravitational potential energy at the surface.



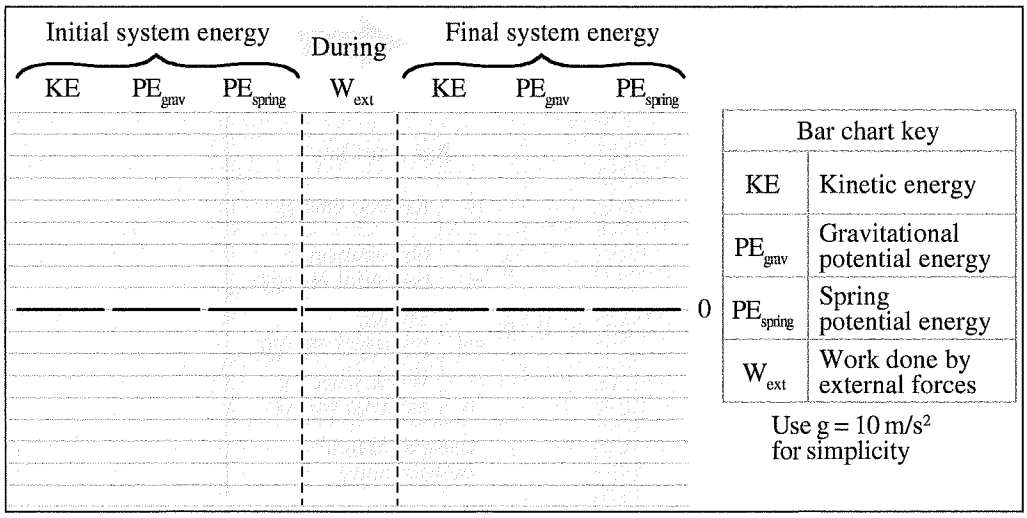
Explain your reasoning.

B4-BCT31: Box Pulled on Rough Surface—Energy Bar Chart

A 100-N box is initially at rest on a rough, horizontal surface where the friction force is 40 N. A student applies a horizontal force of 80 N to the right on the box as shown. The box starts at rest at point *A*.



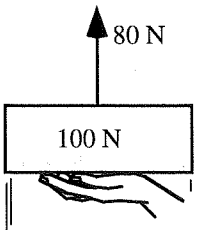
Complete the energy bar chart for the earth-box system before and after the box has moved a horizontal distance of 5.0 m. Put the zero point for the gravitational potential energy at the surface.



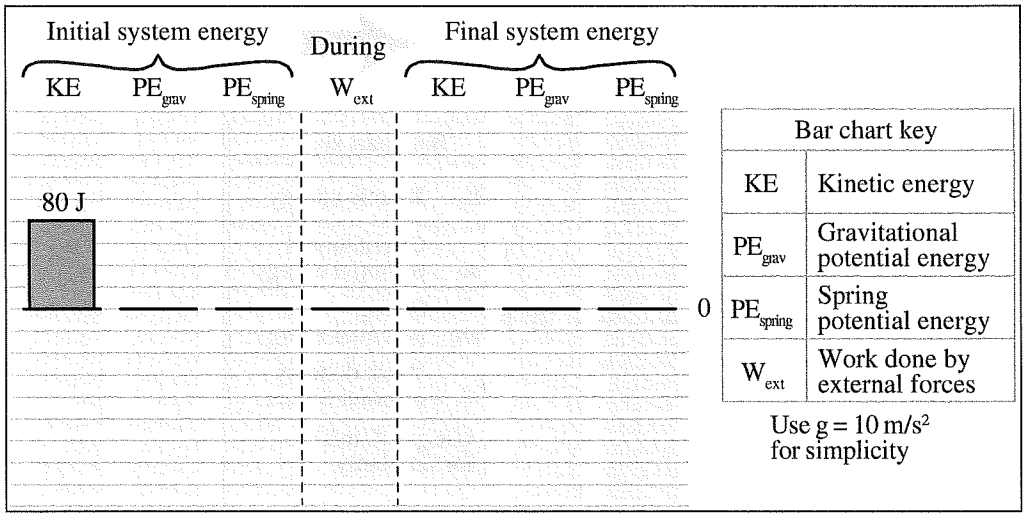
Explain your reasoning.

B4-BCT32: LIFTED BOX MOVING UPWARD I—ENERGY BAR CHART

A 100-N box is initially 0.40 m above the surface of a table and is moving upward with a kinetic energy of 80 J. A man is applying a constant upward force of 80 N with his hand to the box.

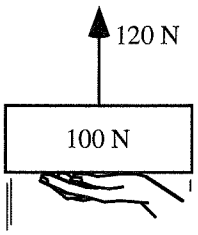


Complete the energy bar chart for the earth-box system before and after the box has moved upward a distance of 1.0 m. Put the zero point for the gravitational potential energy at the surface of the table.



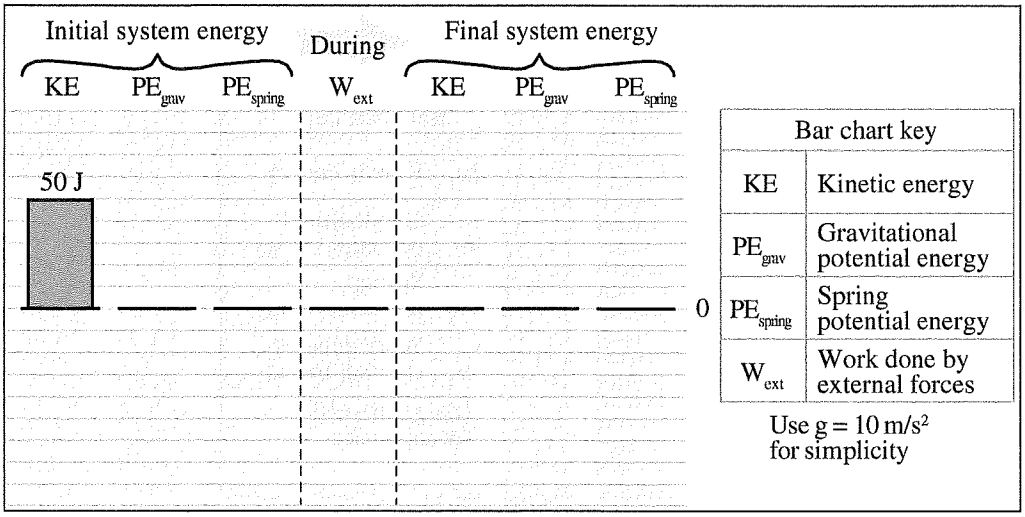
Explain your reasoning.

B4-BCT33: Lifted Box Moving Upward II—Energy Bar Chart I



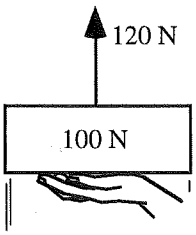
A 100-N box is initially 1.0 m above the ground while moving upward at 10 m/s. A student starts applying a vertical force of 120 N upward with her hand at this point.

Complete the energy bar chart for the earth-box system before and after the box has moved upward a distance of 1.0 m. Put the zero point for the gravitational potential energy at the surface of the ground.



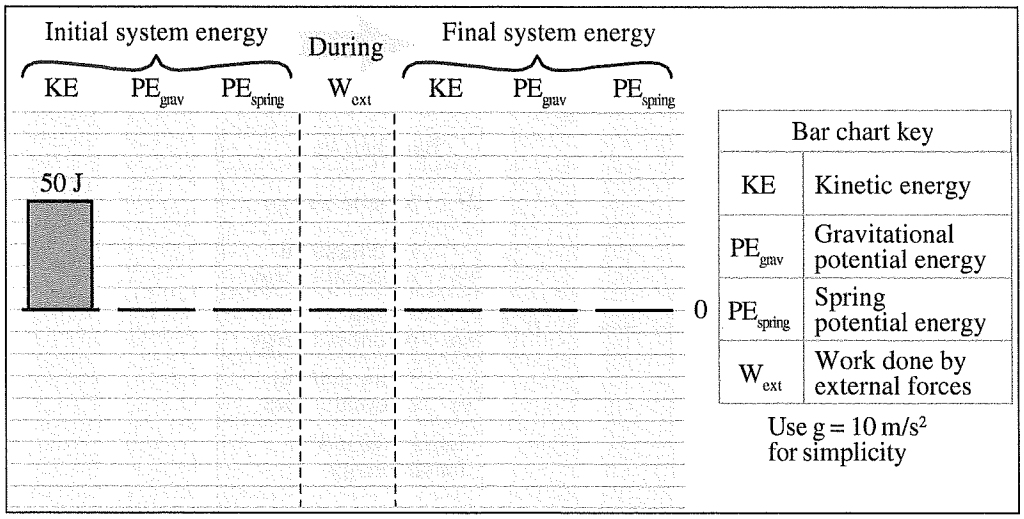
Explain your reasoning.

B4-BCT34: LIFTED BOX MOVING UPWARD II—ENERGY BAR CHART II



A 100-N box is initially 1.0 m above the ground while moving upward at 10 m/s. A student starts applying a vertical force of 120 N upward with her hand at this point.

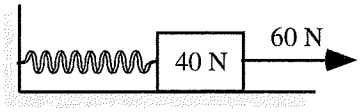
Complete the energy bar chart for the earth-box system before and after the box has moved upward a distance of 1.0 m. Put the zero point for the gravitational potential energy at the final location at 2.0 m above of ground.



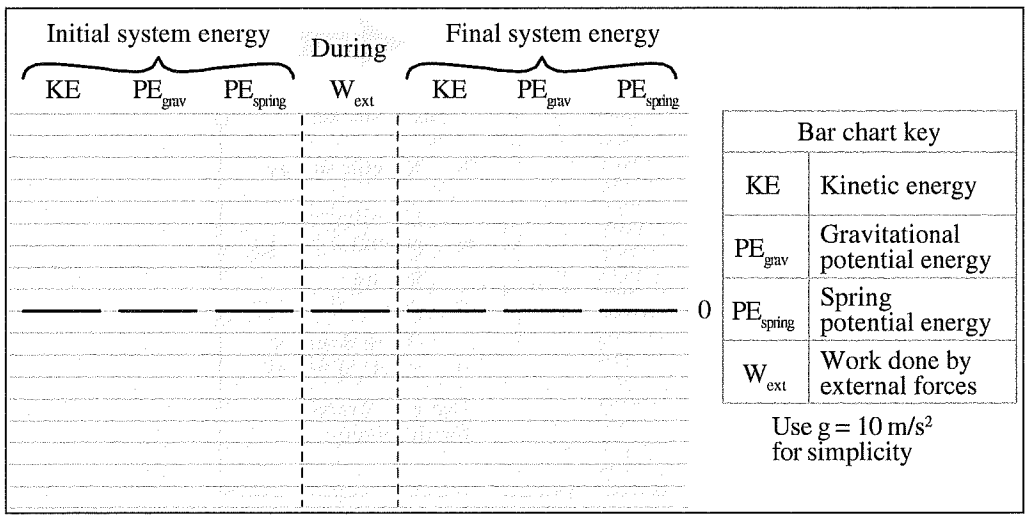
Explain your reasoning.

B4-BCT35: Box Attached to Spring—Energy Bar Chart

A 40-N box is initially at rest on a smooth (frictionless) horizontal surface. An unstretched spring with spring constant 10 N/m connects the box to the wall. A 60 N force is applied horizontally to the right.



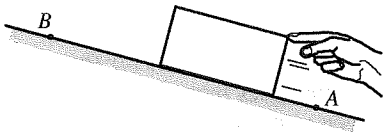
Complete the energy bar chart for the spring-block-earth system as the block moves a distance of 2 m. Label the column heights. Set the zero point for the gravitational potential energy at the center of the block.



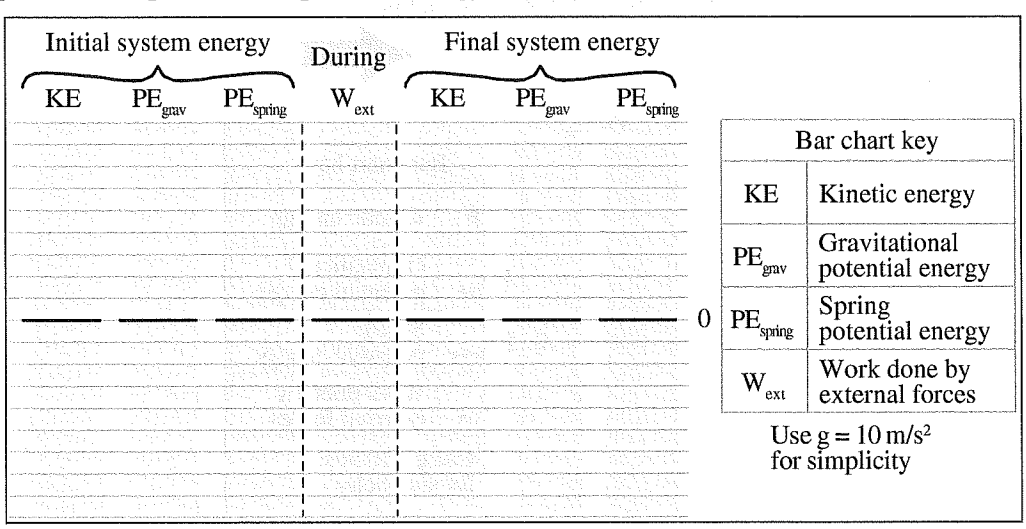
Explain your reasoning.

B4-BCT36: MOVING BLOCK PUSHED UP A SMOOTH RAMP—ENERGY BAR CHART

A moving block is pushed so that it moves up a smooth (frictionless) ramp at increasing speed from *A* to *B*.



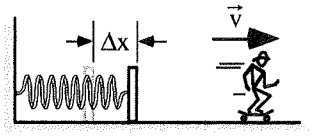
Complete the bar charts for the earth-block system as the block moves from point *A* to *B*. Label the column heights. Set the zero point for the gravitational potential energy of the system at *A*.



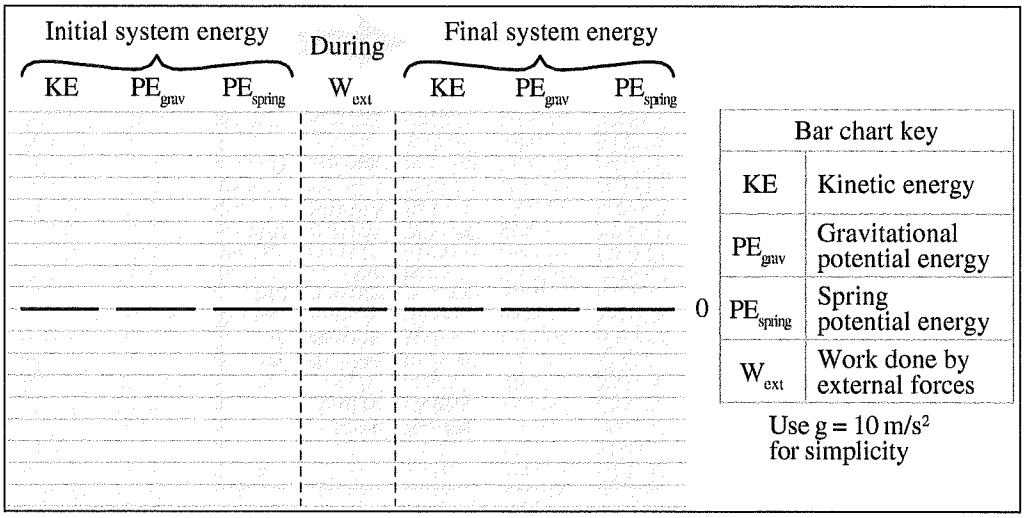
Explain your reasoning.

B4-BCT37: Skateboarder Launched by a Spring I—Energy Bar Chart

A performer on a skateboard is launched by a spring initially compressed a distance Δx. His speed on the horizontal portion of the ramp is v. Ignore friction effects.



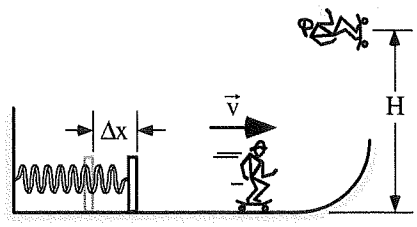
Draw an energy bar chart for the earth-skateboarder-spring system as the skateboarder goes from the compressed spring position at rest to where he moves free of the spring on the horizontal surface. Put the zero point for the gravitational potential energy at the height of the performer before launching.



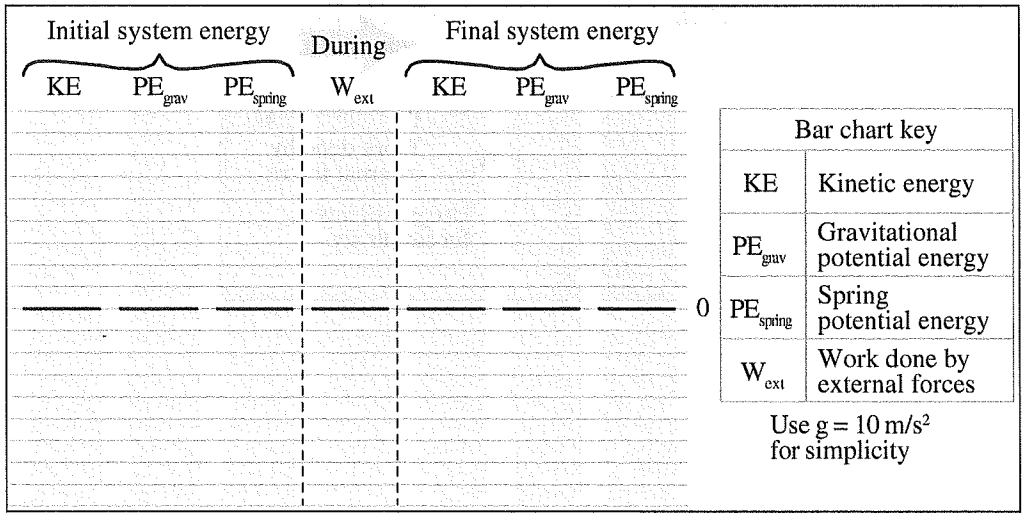
Explain your reasoning.

B4-BCT38: SKATEBOARDER LAUNCHED BY A SPRING II—ENERGY BAR CHART

A performer on a skateboard is launched by a spring initially compressed a distance Δx as shown. His speed on the horizontal portion of the ramp is v, and he rises to a height H after he leaves the ramp. Ignore friction effects.



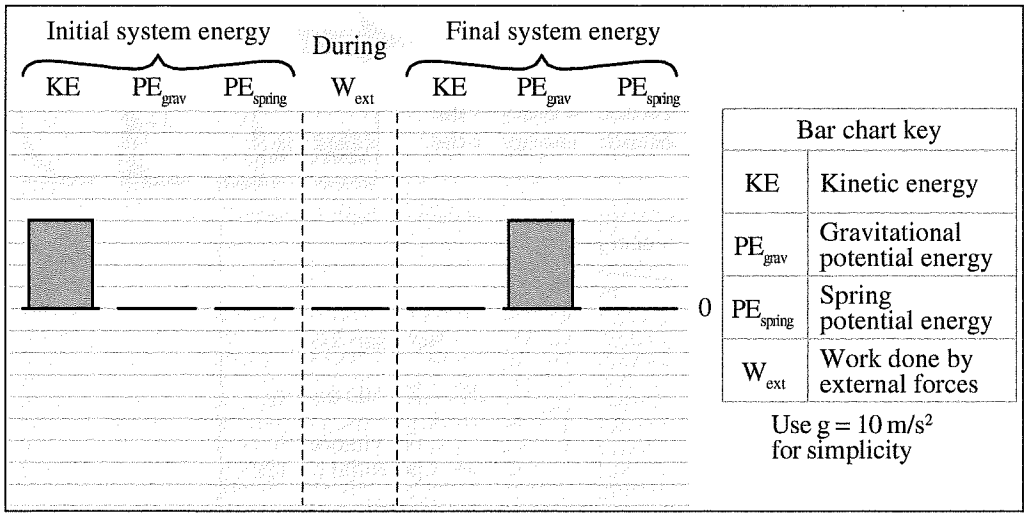
Draw an energy bar chart for the earth- skateboarder-spring system as he goes from the compressed spring position at rest to when he reaches the height H. Put the zero point for the gravitational potential energy at the initial height of the performer before launching.



Explain your reasoning.

B4-WBT39: Energy Bar Chart I—Physical Situation

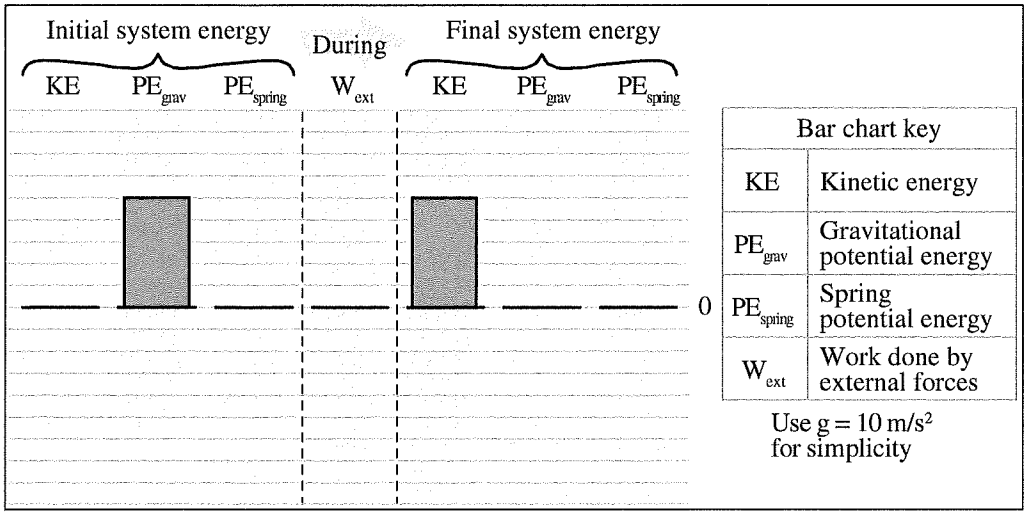
Describe a physical situation and a system to which this energy bar chart could apply.



Explain your reasoning.

B4-WBT40: Energy Bar Chart II—Physical Situation

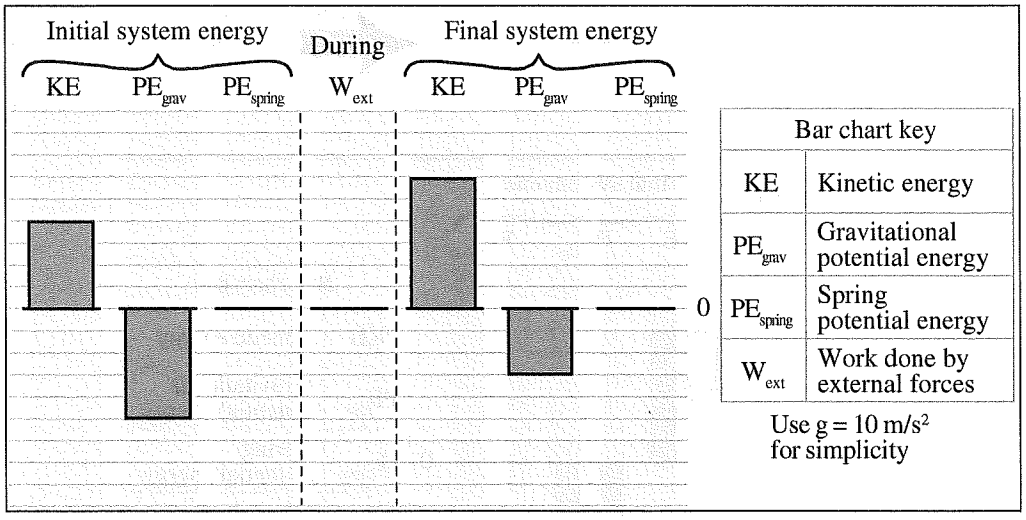
Describe a physical situation and a system to which this energy bar chart could apply.



Explain your reasoning.

B4-WWT41: SLIDING BOX—ENERGY BAR CHART

Shown is an energy bar chart drawn by a student.



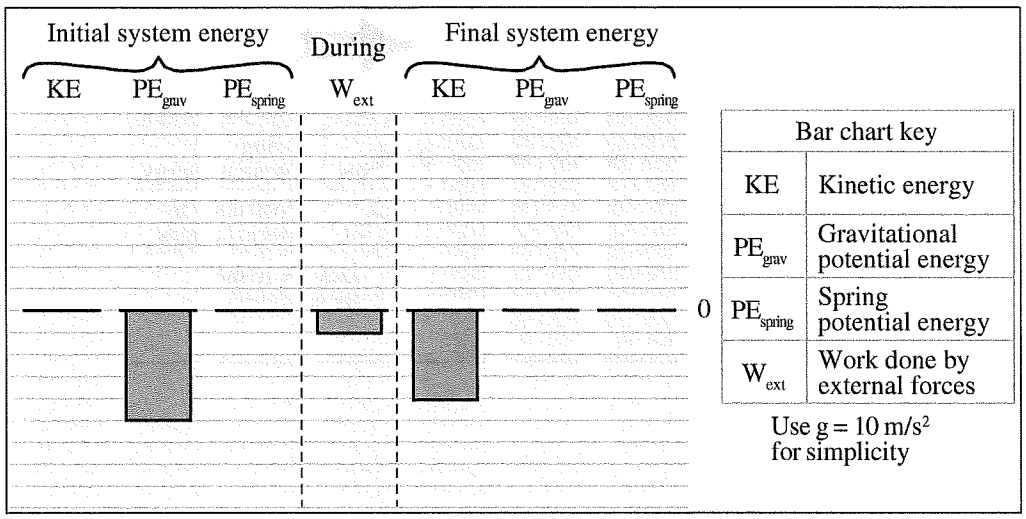
A student who drew this chart says:

"This chart is for a moving box sliding up a smooth slope from a lower point to a higher one. The zero point for the gravitational potential energy is set at the ground level."

What, if anything, is wrong with this chart? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

B4-WWT42: BOX ON SLOPING HILL—ENERGY BAR CHART

Shown is an energy bar chart drawn by a student about a box on a sloping hill.



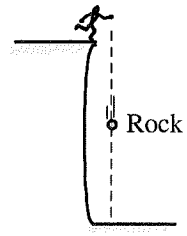
A second student says:

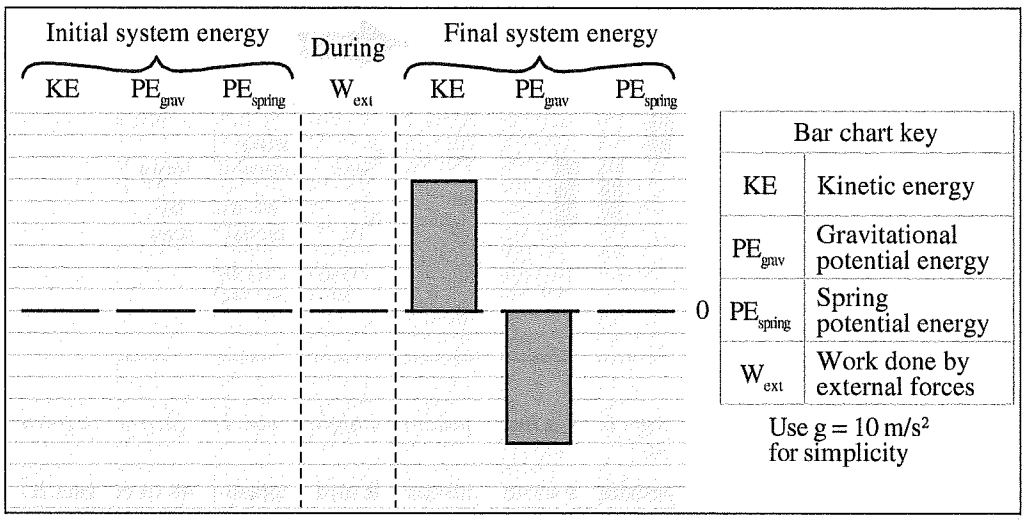
"No, this is not correct since the work done must be positive."

What, if anything, is wrong with this chart? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

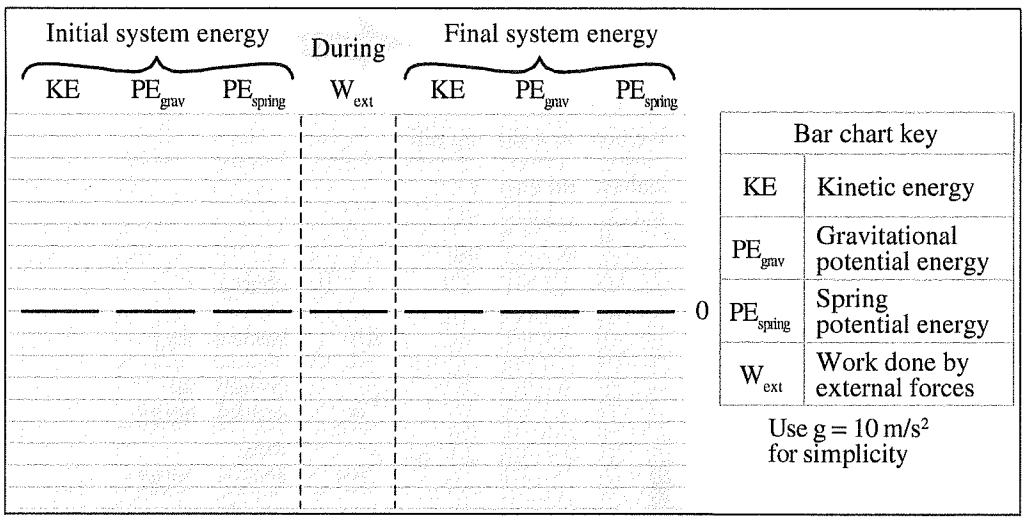
B4-QRT43: Dropped Rock—Energy Bar Chart

A rock is dropped by a student from the top of a cliff and falls straight to the ground below. He constructs an energy bar chart shown below using a coordinate system in which the positive vertical direction is up and the origin of the coordinate system is the release point of the rock which is also selected as the zero point for the gravitational potentials energy.





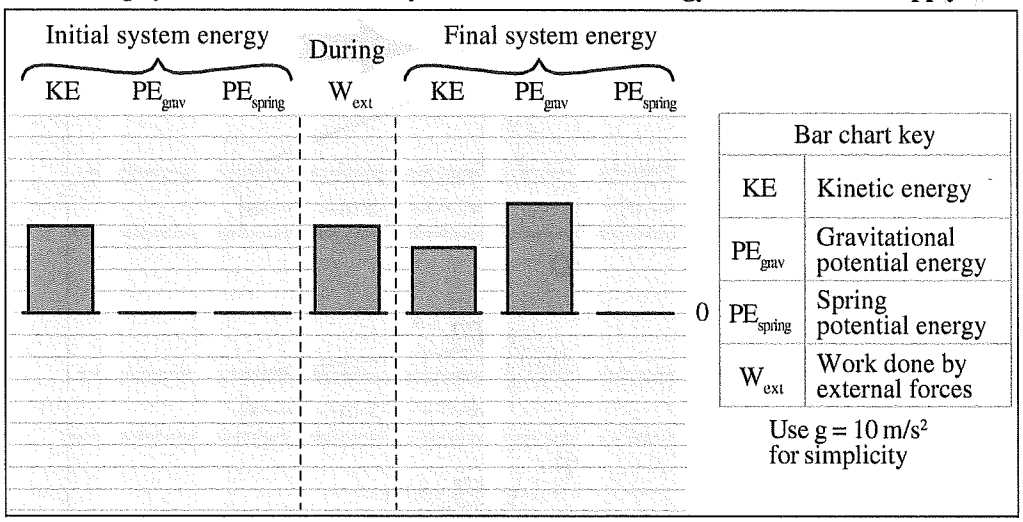
Draw a new energy bar chart for this event but use the ground as the zero point for the potential gravitational energy.



Explain your reasoning.

B4-WBT44: ENERGY BAR CHART—PHYSICAL SITUATION

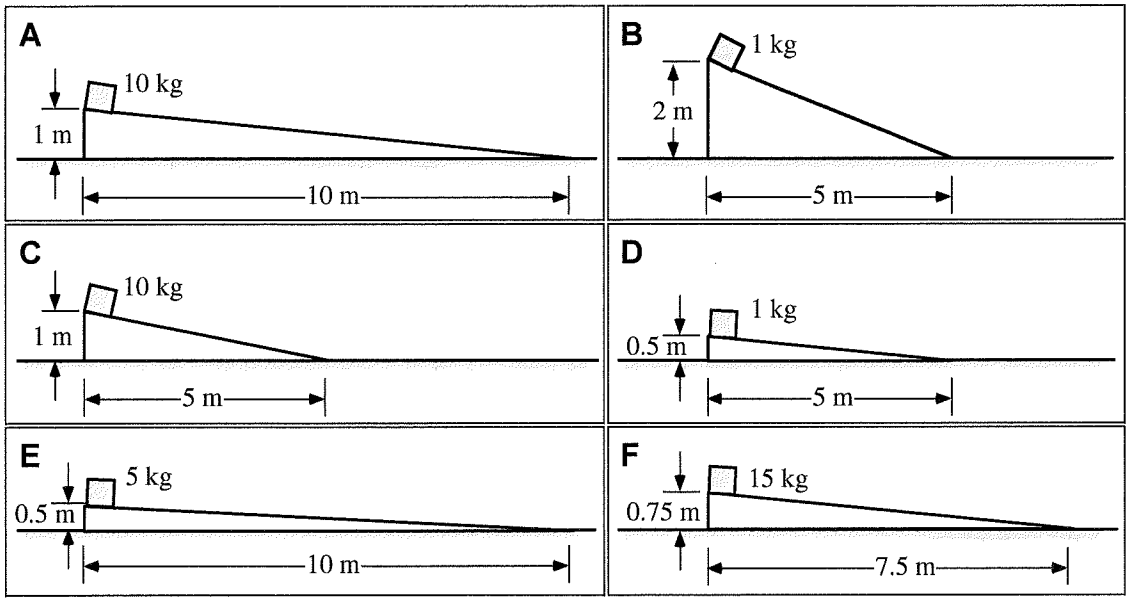
Describe a physical situation and a system to which this energy bar chart could apply.



Explain your reasoning.

B4-RT45: Sliding Masses on Incline—Kinetic Energy

Shown are blocks that slide down frictionless inclines. All masses start from rest at the top of the incline.



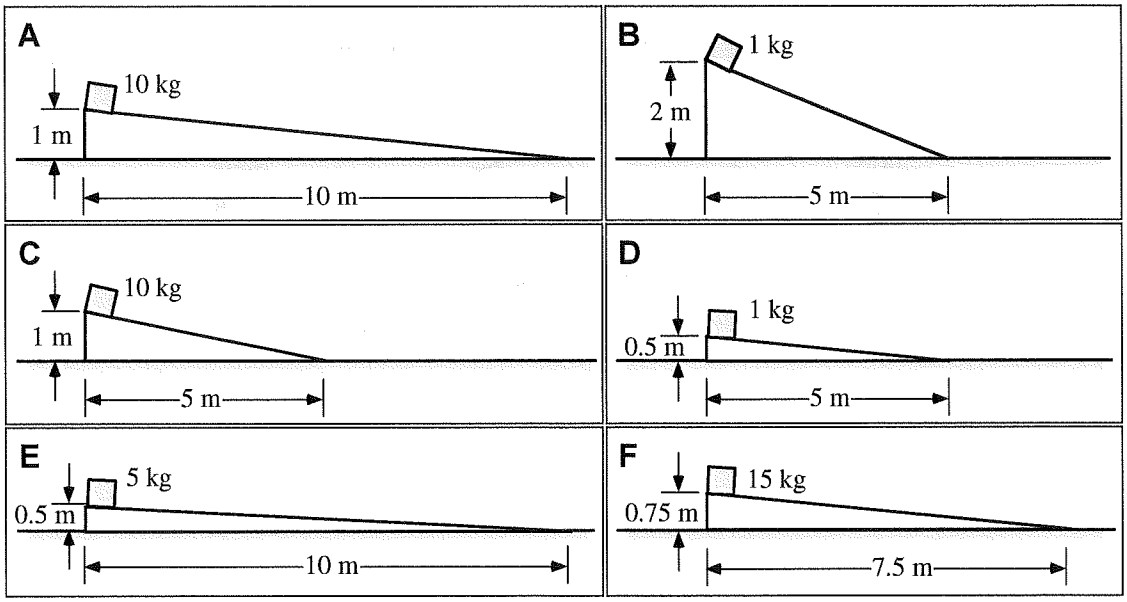
Rank the kinetic energy of the sliding masses the instant they reach the bottom of the incline.

						OR		
1 Greatest	2	3	4	5	6 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B4-RT46: SLIDING MASSES ON INCLINE—CHANGE IN POTENTIAL ENERGY

Shown are blocks that slide down frictionless inclines. All masses start from rest at the top of the incline.



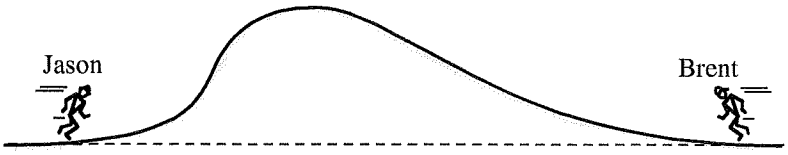
Rank the change in gravitational potential energy of the sliding masses from the top of the incline to the bottom of the incline.

						OR			
							☐	☐	☐
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B4-CT47: Race up a Hill I—Work and Power

Jason and Brent race up a hill that is 30 m high. Jason takes a path that is 60 m while Brent uses a longer path that is 100 m long. It takes Jason 40 seconds, while Brent runs up his path in a shorter time of 30 seconds. They both start from rest at the same height and stop at the top. Also, they have the same weight.



(a) Is the work that Jason does in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Brent does in going up the hill? _____

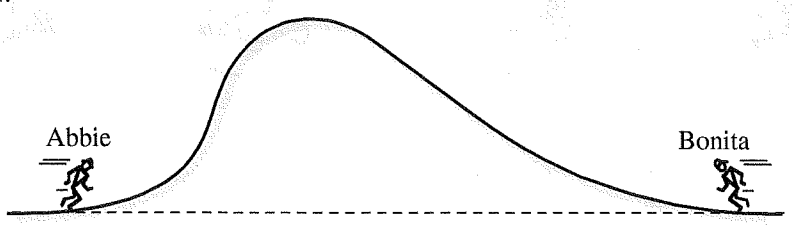
Explain your reasoning.

(b) Is the power generated by Jason in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the power generated by Brent in going up the hill? _____

Explain your reasoning.

B4-CT48: RACE UP A HILL II—WORK AND POWER

Abbie and Bonita decide to race up a hill that is 30 m high. Abbie takes a path that is 60 m long while Bonita uses a path that is 100 m long. It takes Abbie 40 seconds because her route is steep, while Bonita runs up her path in 30 seconds. They both start from rest at the same height and stop at the top. Abbie has a weight of 700 N, and Bonita has a weight of 500 N.



(a) Is the work that Abbie does in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Bonita does in going up the hill? _____

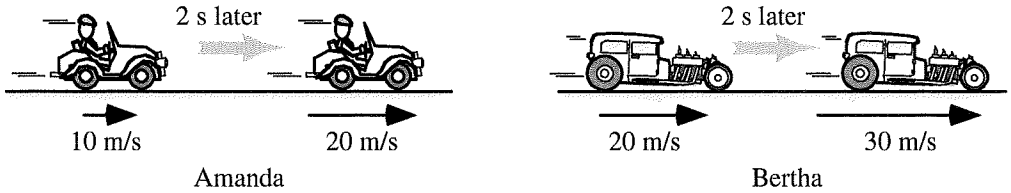
Explain your reasoning.

(b) Is the power generated by Abbie in going up the hill *greater than*, *less than*, or *the same as* the power generated by Bonita in going up the hill? _____

Explain your reasoning.

B4-CT49: Car Race—Work and Power

Amanda and Bertha are in a car race. Their cars have the same mass. At one point in the race, they both change their speeds by 10 m/s in 2 seconds. Ignore air friction.



(a) Is the work that Amanda's car does while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Bertha's car does while speeding up? _____

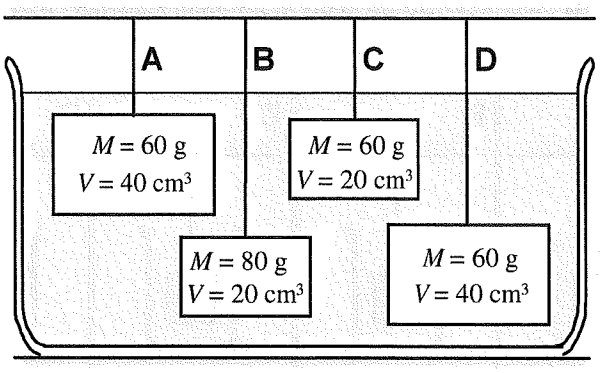
Explain your reasoning.

(b) Is the power generated by Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the power generated by Bertha's car while speeding up? _____

Explain your reasoning.

C2-RT03: Blocks Suspended in Water at Different Depths—Buoyant Force

Blocks that have different masses and volumes are suspended by strings in water. The blocks are at two different depths below the surface as shown.



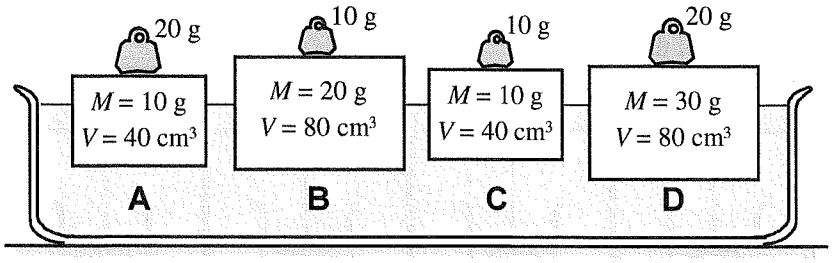
Rank the buoyant force exerted on the blocks by the water.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT04: Floating Blocks with Different Loads—Buoyant Force

Wood blocks that have different masses and different volumes are floating in water. On top of these blocks are additional masses as shown.



Rank the buoyant force exerted by the water on the wood blocks.

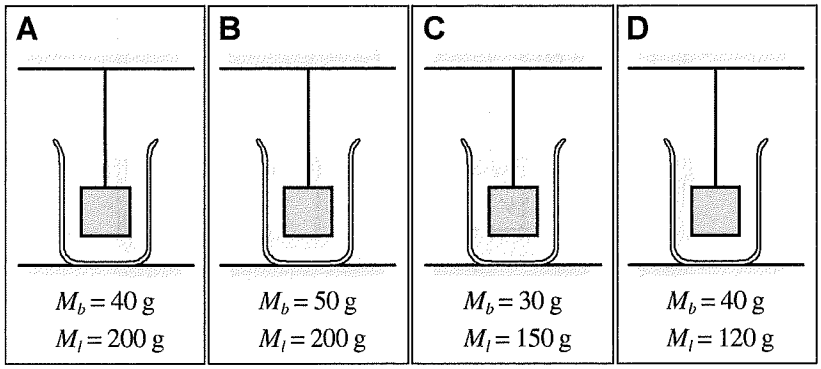
☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2 FLUIDS

C2-RT01: BLOCKS SUSPENDED IN LIQUIDS—BUOYANT FORCE

In each case, a block hanging from a string is suspended in a liquid. All of the blocks are the same size, but they have different masses (labeled M_b) because they are made of different materials. All of the containers have the same volume of liquid, but the masses of these liquids vary (labeled M_l) since the liquids are different. The volume of the blocks is one-sixth the volume of the liquids.



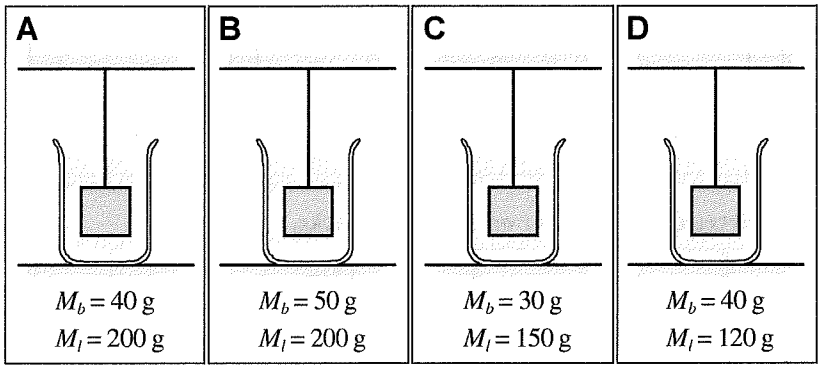
Rank the buoyant forces on the blocks.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT02: BLOCKS SUSPENDED IN LIQUIDS—VOLUME OF LIQUID DISPLACED

In each case, a block hanging from a string is suspended in a liquid. All of the blocks are the same size, but they have different masses (labeled M_b) because they are made of different materials. All of the containers have the same volume of liquid, but the masses of these liquids vary (labeled M_l) since the liquids are different. The volume of the blocks is one-sixth the volume of the liquids.



Rank the volume of the liquid displaced by the blocks.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

C1-WWT10: Pouring Liquid Between Beakers—Density

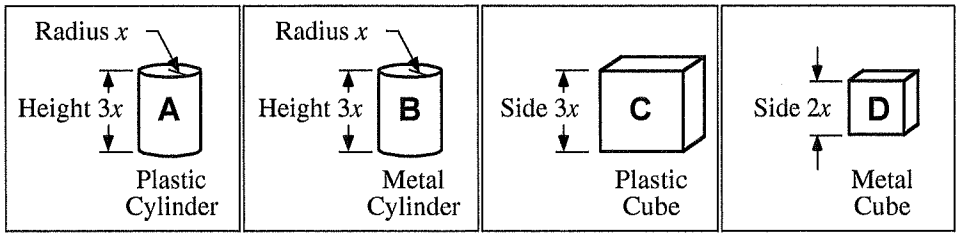
A liquid in a tall, narrow cylindrical beaker is poured into a wider cylindrical beaker. The liquid only fills the wider beaker to one-fourth its height in the tall beaker. A student makes the following statement:

"When the liquid was poured from the narrow beaker into the wider one, the volume changed. Since no liquid was spilled, all of the liquid is still in the wider beaker, so the density of the liquid must have changed."

What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

C1-RT08: CYLINDERS AND CUBES—DENSITY

A cylinder and a cube are carved out of a piece of plastic with uniform density, and a second cylinder and cube are carved out of a piece of metal with uniform density. Dimensions are given for the cylinders and cubes. The mass of the cylinder in Case B is twice the mass of the cylinder in Case A.



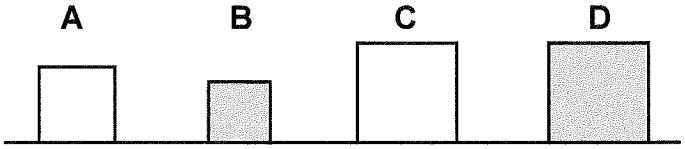
Rank the densities of the objects.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C1-QRT09: FOUR CUBES—MASS

Of the four cubes shown below, white cubes A and C are made of the same material, and gray cubes B and D are made of the same material. Each cube has a uniform density. The ranking of cube size is C = D > A > B. Cubes A and B have the same mass.

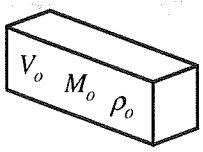


Is the mass of cube C (i) *greater than*, (ii) *less than*, or (iii) *equal to* the mass of cube D?

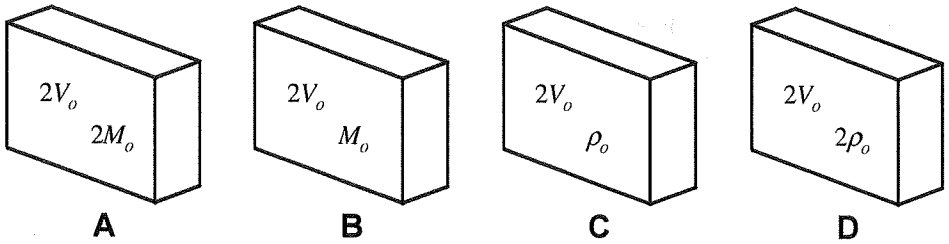
Explain your reasoning.

C1-BCT07: Four Blocks—Mass and Density

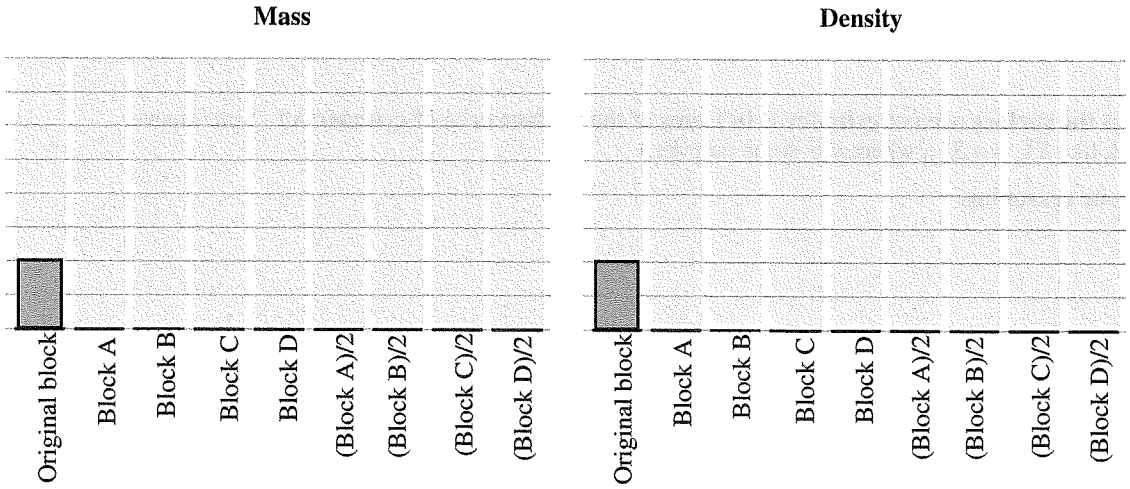
The block of material shown to the right has a volume V_o. An overall mass M_o is distributed evenly throughout the volume of the block so that the block has a uniform density ρ_o.



For each block shown below, the volume is given as well as *either* the mass or the density of the block.



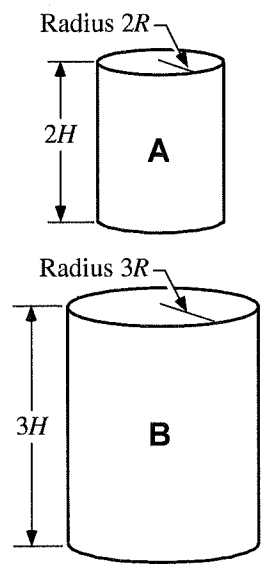
Construct bar charts for the mass and density for the four blocks labeled A–D, and for the pieces of the blocks if they were cut in half labeled A/2–D/2. The mass and density for the original block are shown to set the scale of the chart.



Explain your reasoning.

C1-QRT06: CYLINDERS WITH THE SAME MASS III—VOLUME, AREA, AND DENSITY

Two solid cylinders are shown. Cylinder A has a height $2H$ and a radius $2R$ and cylinder B has a height $3H$ and a radius $3R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.



If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi rh$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

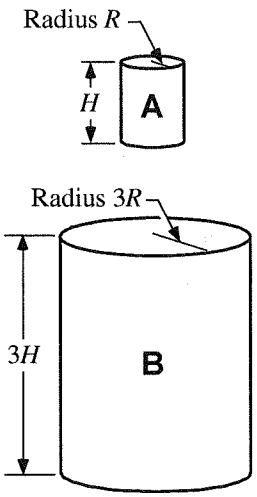
Explain your reasoning.

(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

Explain your reasoning.

C1-QRT05: Cylinders with the Same Mass II—Volume, Area, and Density

Two solid cylinders are shown. Cylinder A has a height H and a radius R and cylinder B has a height $3H$ and a radius $3R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.



If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi r h$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

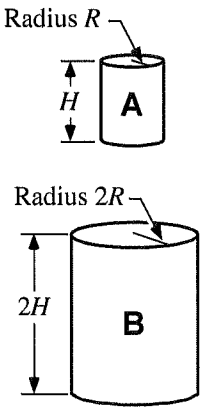
Explain your reasoning.

(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

Explain your reasoning.

C1-QRT04: CYLINDERS WITH THE SAME MASS I—VOLUME, AREA, AND DENSITY

Two solid cylinders are shown. Cylinder A has a height H and a radius R, and cylinder B has a height $2H$ and a radius $2R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.



If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi rh$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

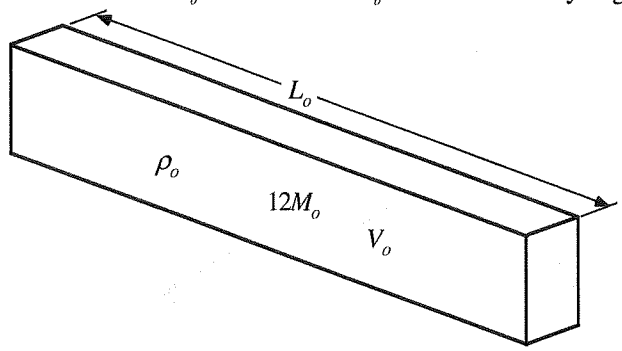
Explain your reasoning.

(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

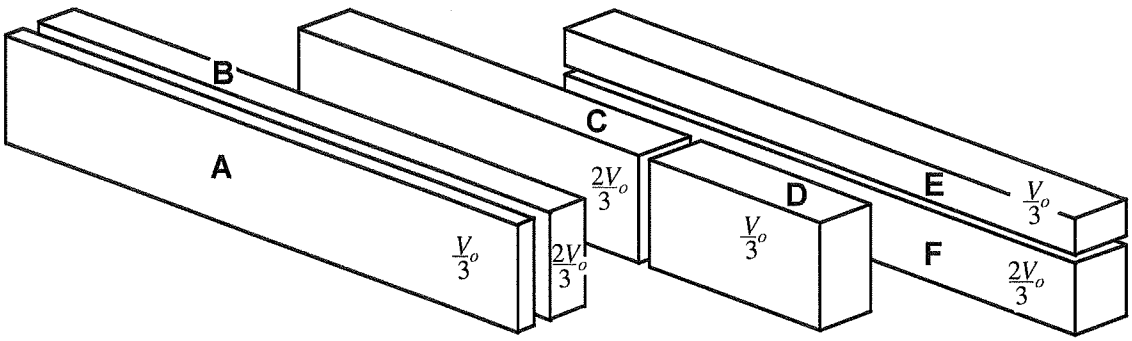
Explain your reasoning.

C1-QRT03: Slicing up a Block—Mass and Density

The plastic block shown below has a volume V_o and a mass $12M_o$ distributed evenly to give a uniform density ρ_o.



Three possible ways to slice the plastic block into unequal pieces are shown below. In each case, the larger piece has a volume $2V_o/3$ and the smaller piece has a volume $V_o/3$.



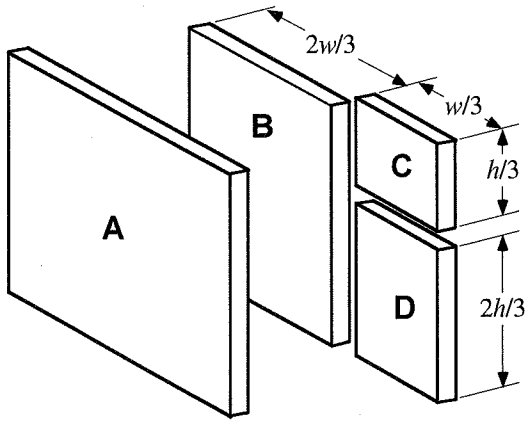
Fill in the table for the mass (in terms of M_o) and density (in terms of ρ_o) of the pieces of the block labeled A– F.

	Mass	Density
Original block		
Piece A		
Piece B		
Piece C		
Piece D		
Piece E		
Piece F		

C1 DENSITY

C1-RT01: CUTTING UP A BLOCK—DENSITY

A block of material (labeled A in the diagram) with a width w, height h, and thickness t has a mass of M_o distributed uniformly throughout its volume. The block is then cut into three pieces, B, C, and D, as shown.



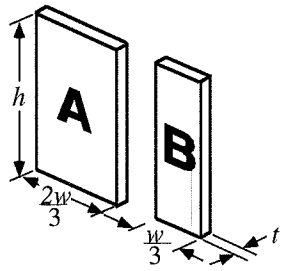
Rank the density of the original block A, piece B, piece C, and piece D.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C1-SCT02: BREAKING UP A BLOCK—DENSITY

A block of material with a width w, height h, and thickness t has a mass of M_o distributed uniformly throughout its volume. The block is then broken into two pieces, A and B, as shown. Three students make the following statements:



Ajay: *"They both have the same density. It's still the same material."*

Ben: *"The density is the mass divided by the volume, and the volume of B is smaller. Since the mass is uniform and the volume is in the denominator, the density is larger for B."*

Chithra: *"The density of piece A is larger than the density of piece B since A is larger; thus it has more mass."*

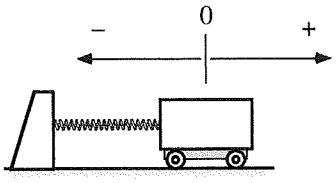
With which, if any, of these students do you agree?

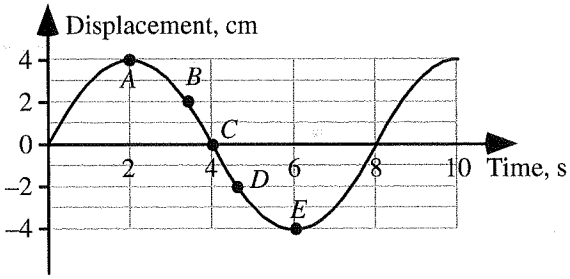
Ajay _____ Ben _____ Chithra _____ None of them_____

Explain your reasoning.

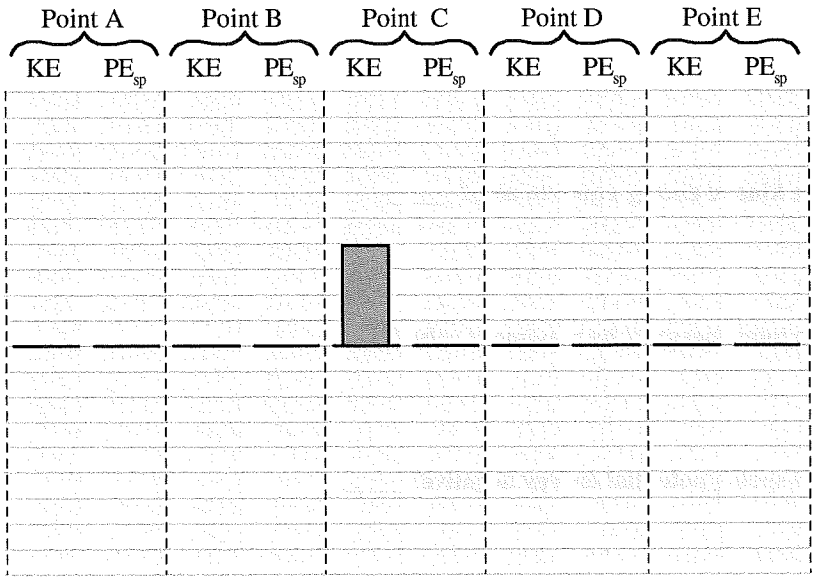
B7-BCT14: Oscillating Mass on Spring Displacement-Time Graph—Energy

A cart attached to a spring is given an initial push, displacing it from its equilibrium position. A graph of displacement as a function of time for the cart is shown at right. The system has a total initial energy of 12 J and there is no friction. Five points are labeled *A–E* in the graph.





For each labeled point, complete the bar chart below for the kinetic energy and the potential energy for the cart-spring system.

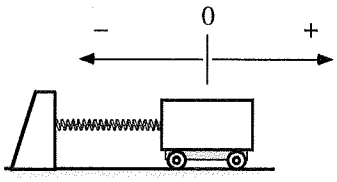


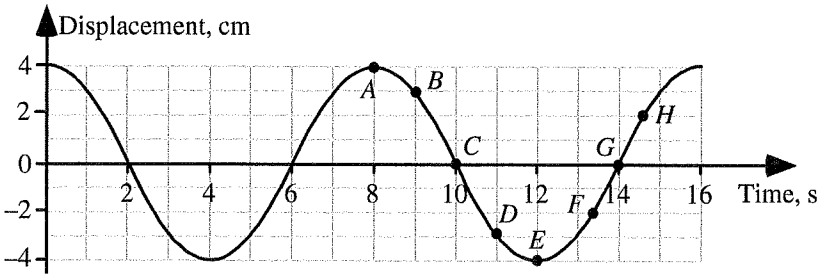
Bar chart key	
KE	Kinetic energy
PE$_{spring}$	Spring potential energy

Explain your reasoning.

B7-QRT13: DISPLACEMENT-TIME GRAPH—ENERGY QUANTITIES

A cart attached to a spring is displaced from equilibrium and then released. A graph of displacement as a function of time for the cart is shown. There is no friction. Points are labeled *A–H* in the graph.





For each question below, choose from the labeled points above or state "none" for the mass-spring-earth system.

(a) At which point or points are the spring potential energy and the cart's kinetic energy both at their maximum values? _____
Explain your reasoning.

(b) At which point or points is the kinetic energy equal to zero? _____
Explain your reasoning.

(c) At which point or points is the total energy at its maximum value? _____
Explain your reasoning.

(d) At which point or points is the spring potential energy negative? _____
Explain your reasoning.

(e) At which point or points is the kinetic energy positive? _____
Explain your reasoning.

(f) At which point or points is the kinetic energy at its maximum value and the spring potential energy at its minimum value? _____
Explain your reasoning.

(g) At which point or points is the kinetic energy at its minimum value and the spring potential energy at its maximum value? _____
Explain your reasoning.

B7-SCT12: Mass Oscillating on a Vertical Spring—Energy

A mass hanging on a vertical spring is pulled down a distance *d* and released. The mass undergoes simple harmonic motion. Three physics students make the following contentions about this situation:

Alexandra: *"The maximum kinetic energy of this mass-spring system is fixed by the properties of the system and does not depend on how far down the mass is pulled. How far the mass is pulled will only affect the frequency of the oscillations."*

Bruno: *"No, that can't be right since increasing the amplitude, or how far down it is pulled, increases the potential energy of the system. I don't think the amplitude has any effect on the frequency."*

Chung: *"I agree in part with both of you. I think the amplitude does affect the maximum kinetic energy, but I also think it affects the frequency of the oscillations."*

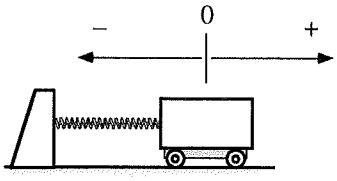
With which, if any, of these students do you agree?

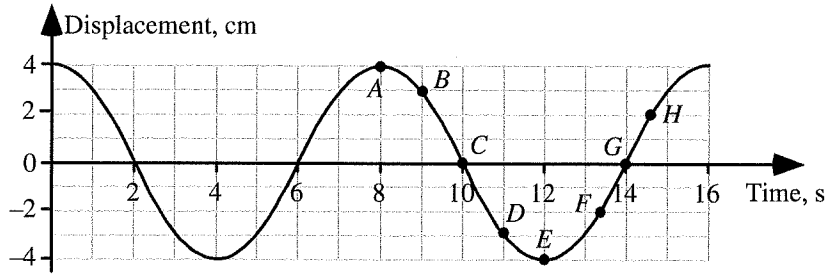
Alexandra _____ Bruno _____ Chung _____ None of them_____

Explain your reasoning.

B7-QRT11: OSCILLATING MASS ON SPRING DISPLACEMENT-TIME GRAPH—DIRECTIONS

A cart attached to a spring is displaced from equilibrium and then released. A graph of displacement as a function of time for the cart is shown. There is no friction. Points are labeled *A–H* in the graph. The arrows and signs above the cart indicate the positive and negative directions for the displacement of the cart.





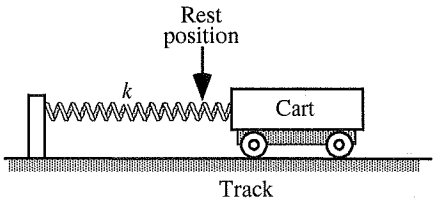
For each labeled point above, identify if the vector quantity listed below is in the positive (+) direction, negative (–) direction, or is zero (0) for no direction.

Point	Acceleration	Velocity	Displacement	Net Force
A				
B				
C				
D				
E				
F				
G				
H				

Explain your reasoning.

B7-SCT10: Horizontal Oscillating Cart—Period

A frictionless cart of mass M is attached to a spring with spring constant k. When the cart is displaced 6 cm from its rest position and released, it oscillates with a period of 2 seconds.



Four students are discussing what would happen to the period of oscillation if the original cart with mass M was displaced 12 cm from its rest position instead of 6 cm and again released:

Adan: *"Since the spring is stretched more, the force will be greater, causing a greater acceleration and greater speeds overall. Since the cart is moving faster, the time will go down, probably to 1 second since the force is doubled."*

Barb: *"The cart has farther to go now, and so it's going to take longer to make a complete cycle. It's going to go farther on both sides of the rest position, so the round-trip is 48 cm instead of 24 cm. The period is going to double."*

Charles: *"The cart has four times as much energy, and the conjugate variable for energy is time according to the Heisenberg uncertainty principle. The energy quadruples when the spring stretch is doubled, and so the time must be only one-quarter as much. The period will be one-half second."*

Dallas: *"Stretching the spring twice as far means that k is twice as big. And the period is 2 pi times the square root of the spring constant divided by the mass. Doubling the spring constant and leaving the mass alone is going to double what's inside the square root, and after we take the square root we get a period of 2 seconds times the square root of 2, or 1.414 seconds."*

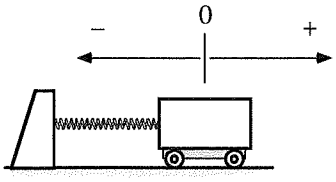
With which, if any, of these students do you agree?

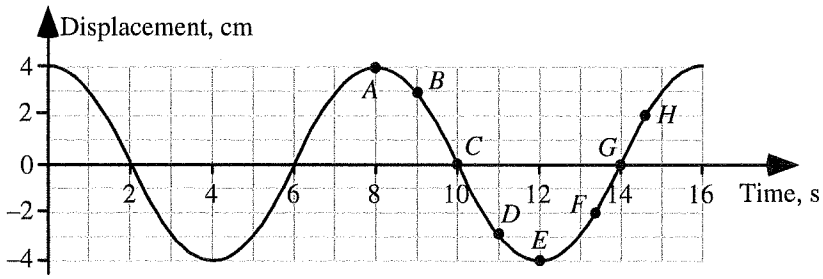
Adan _____ Barb _____ Charles _____ Dallas _____ None of them_____

Explain your reasoning.

B7-QRT09: OSCILLATION DISPLACEMENT-TIME GRAPH—KINEMATIC QUANTITIES

A cart attached to a spring is displaced from equilibrium and then released. There is no friction. A graph of displacement as a function of time for the cart is shown. The arrows and signs above the cart indicate the positive and negative directions for the position of the cart.





For each question below, choose from the labeled points above, or state "none."

(a) At which point or points is the acceleration positive? _____
Explain your reasoning.

(b) At which point or points does the cart have zero velocity but nonzero net force? _____
Explain your reasoning.

(c) At which point or points is the net force on the cart equal to zero? _____
Explain your reasoning.

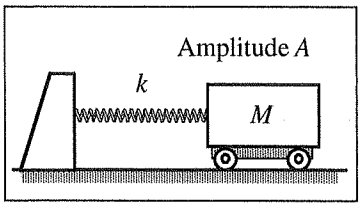
(d) At which point or points are the acceleration, velocity, and displacement all positive? _____
Explain your reasoning.

(e) At which point or points is the acceleration nonzero and opposite in sign to the position? _____
Explain your reasoning.

(f) At which point or points is the velocity nonzero and opposite in sign to the acceleration? _____
Explain your reasoning.

B7-LMCT08: Mass Connected to a Horizontal Spring—Frequency

A mass-spring system consists of a spring with a spring constant (or stiffness) k and unstretched length L, connected to a cart of mass M resting on a horizontal frictionless surface as shown. If the cart is pulled to one side a small distance and released, it will oscillate back and forth with amplitude A and frequency f.



Identify from choices (i)–(iv) how each change described below will affect the frequency of the oscillating mass-spring system.

Compared to the case above, this change will:

(i) ***increase*** the frequency of the system.
(ii) ***decrease*** the frequency of the system.
(iii) ***have no effect*** on the frequency of the system.
(iv) *have an* ***indeterminate*** effect on the frequency of the system.

Each of these modifications is the only change to the initial situation described above.

(a) The mass is increased. _____
Explain your reasoning.

(b) The spring constant or stiffness is increased. _____
Explain your reasoning.

(c) The mass is pulled a little farther and then released. _____
Explain your reasoning.

(d) The spring constant is doubled to $2k$ and the mass is reduced to $M/2$. _____
Explain your reasoning.

(e) The amplitude is increased and the mass is increased. _____
Explain your reasoning.

B7-SCT07: MASS ON A VERTICAL SPRING—ACCELERATION

A mass is oscillating up and down at the end of a spring. Three students are discussing the acceleration of the mass:

Aileen: *"I think the acceleration of the mass will be largest when it is at the end of its oscillations turning around. That's where the spring is stretched the most."*

Brigitte: *"No, I don't see how that can be. Its velocity is zero at that point, so its acceleration has to be zero also."*

Chandra: *"I disagree. The acceleration is largest when the mass is halfway between the middle and the end because that is where its speed is changing the most."*

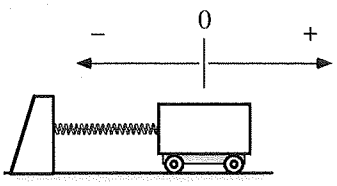
With which, if any, of these students do you agree?

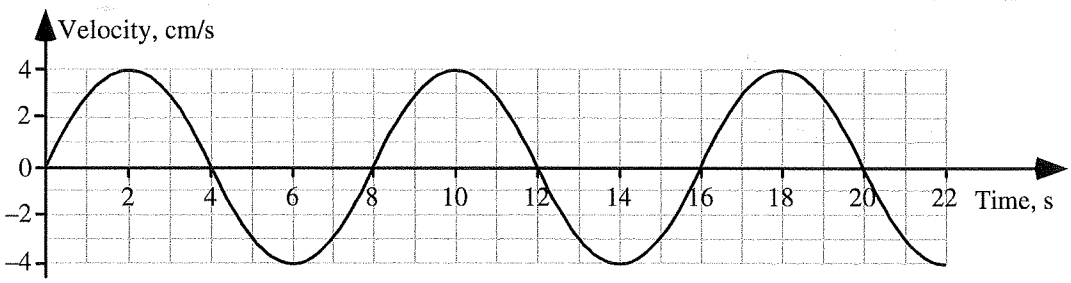
Aileen _____ Brigitte _____ Chandra _____ None of them_____

Explain your reasoning.

B7-CRT06: Velocity-Time Graph—Frequency and Period

A cart attached to a spring is displaced from equilibrium and then released. There is no friction. A graph of velocity as a function of time for the cart is shown. The arrows and signs above the cart indicate the positive and negative directions for the position of the cart.





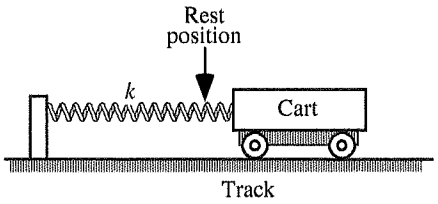
(a) What is the period of the motion for this cart?
Explain your reasoning.

(b) What is the frequency of the motion for this cart?
Explain your reasoning.

(c) In which direction was the cart displaced from equilibrium before it was released?
Explain your reasoning.

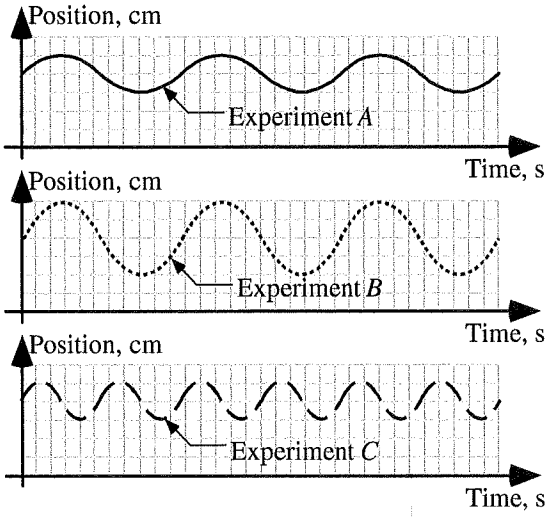
B7-QRT05: POSITION-TIME GRAPH OF A CART ATTACHED TO A SPRING—MASS AND PERIOD

A frictionless cart of mass m is attached to a spring with spring constant k. When the cart is displaced from its rest position and released, it oscillates with a period τ that is given by



$$\tau = 2\pi\sqrt{m/k}$$

The graph of the position of this cart as a function of time is labeled Experiment A. Graphs for two other experiments that use different masses are shown below this. The same spring is used in all three experiments.



(a) Compared to Experiment *A*, in Experiment *B* the cart has

(i) *twice* as much mass.

(ii) *four times* as much mass.

(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

(b) Compared to Experiment *A*, in Experiment *C* the cart has

(i) *twice* as much mass.

(ii) *four times* as much mass.

(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

(c) Suppose that in a fourth experiment (Experiment *D*), the mass used in Experiment *A* was doubled and the spring was replaced with a spring with spring constant $2k$. The period in Experiment *D* would be

(i) *the same* as the period in Experiment A.

(ii) *double* the period in Experiment A.

(iii) *four times* the period in Experiment A.

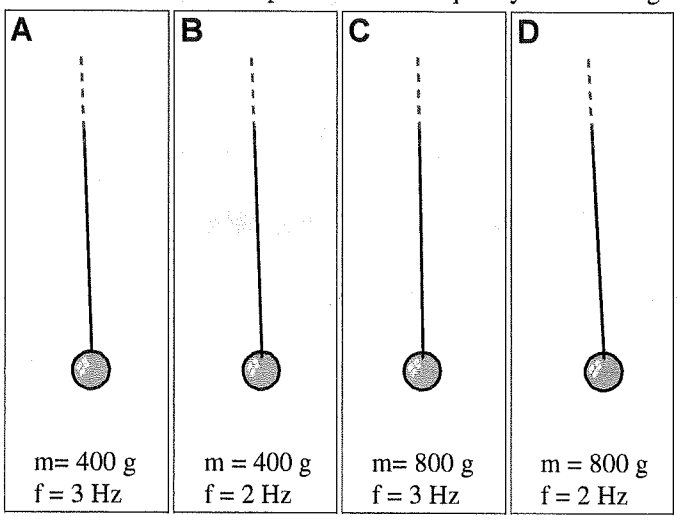
(iv) *one-half* the period in Experiment A.

(v) *one-fourth* the period in Experiment A.

Explain your reasoning.

B7-RT03: Swinging Sphere on Long Strings—Time for One Swing

Metal spheres are hung on the ends of long strings. The spheres have been pulled to the side and released so that they are swinging back and forth. The mass of the sphere and the frequency of the swing are given in each case.



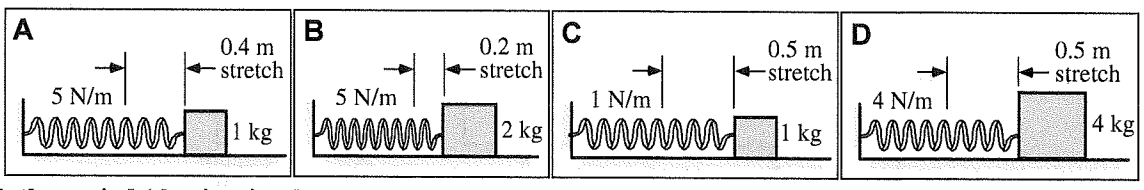
Rank the time it takes to make one complete swing.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B7-RT04: Mass on Horizontal Spring Systems II—Period of Oscillating Mass

A block rests on a frictionless surface and is attached to the end of a spring. The other end of the spring is attached to a wall. Four block–spring systems are considered. The springs are stretched to the right by the distances shown in the figures and then released from rest. The blocks oscillate back and forth. The mass and force constant of the spring are given for each case.



Rank the period (the time it takes the block to complete one cycle) of the oscillatory motion of the block.

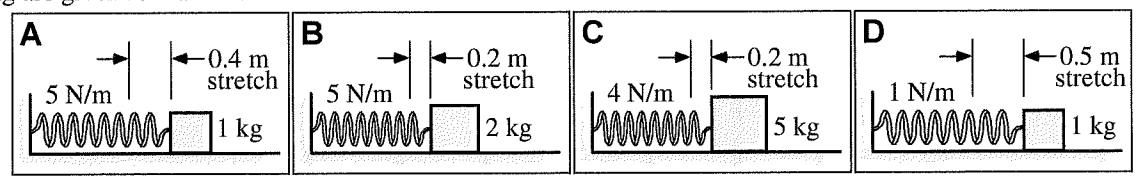
				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B7 OSCILLATORY MOTION

B7-RT01: MASS ON HORIZONTAL SPRING SYSTEMS I—OSCILLATION FREQUENCY

A block rests on a frictionless surface and is attached to the end of a spring. The other end of the spring is attached to a wall. Four block–spring systems are considered. The springs are stretched to the right by the distances shown in the figures and then released from rest. The blocks oscillate back and forth. The mass and force constant of the spring are given for each case.



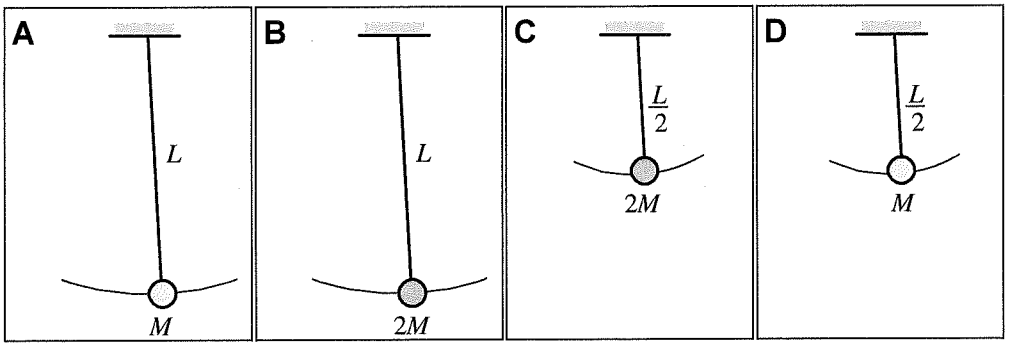
Rank the frequency of the oscillatory motion of the block.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B7-RT02: SWINGING SIMPLE PENDULA—OSCILLATION FREQUENCY

The simple pendulum shown in Case A consists of a mass M attached to a massless string of length L. If the mass is pulled to one side a small distance and released, it will swing back and forth. Cases B, C, and D are variations of this system.



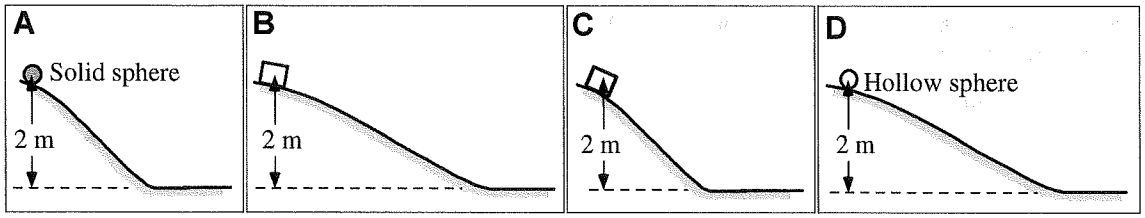
Rank the oscillation frequency of the masses.

				OR	
1 Greatest	2	3	4 Least	All the same	Cannot determine

Explain your reasoning.

B6-RT31: Objects Moving down Ramps—Speed at Bottom

In each case, a 1-kg object is released from rest on a ramp at a height of 2 m from the bottom. All of the spheres roll without slipping, and the blocks slide without friction. The ramps are identical in Cases A and C. The ramps in Cases B and D are identical and are not as steep as the others.



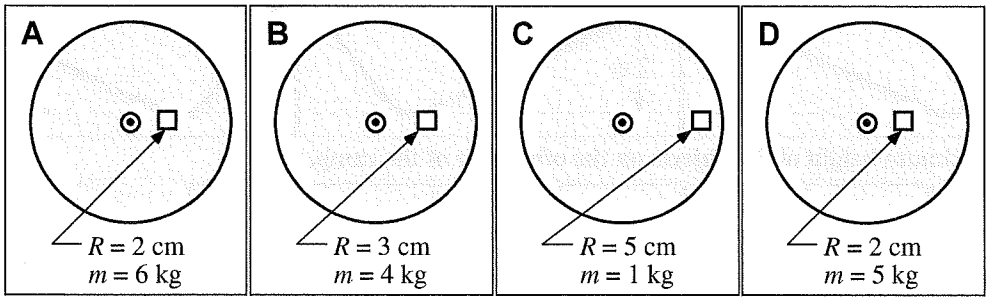
Rank the speed of the objects when they reach the horizontal surface at the bottom of the ramp.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B6-RT32: Blocks on Rotating Disc—Horizontal Frictional Force

A block is placed on a rotating disc and moves in a circular path. The discs have the same rotation rate in each case, but the masses of the blocks and their distance from the center varies.



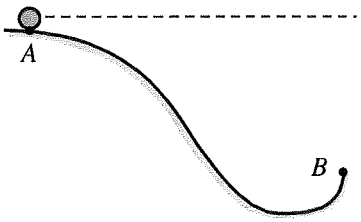
Rank the magnitude of the frictional force on blocks by the discs.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT29: SOLID SPHERE ROLLING ALONG A TRACK—LOCATION AT HIGHEST POINT

A solid sphere rolls without slipping along a track shaped as shown at right. It starts from rest at point *A* and is moving vertically when it leaves the track at point *B*.

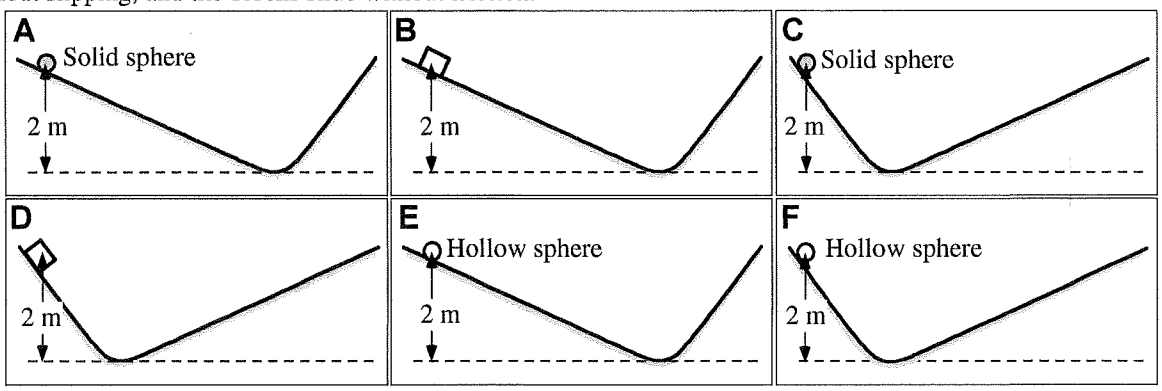


At its highest point while in the air, will the sphere be (a) *above*, (b) *below*, or (c) *at the same height as* point *A*? _____

Explain your reasoning.

B6-RT30: MOVING DOWN A RAMP—MAXIMUM HEIGHT ON THE OTHER SIDE OF A RAMP

In each case, a 1-kg object is released from rest on a ramp at a height of 2 m from the bottom. All of the spheres roll without slipping, and the blocks slide without friction.



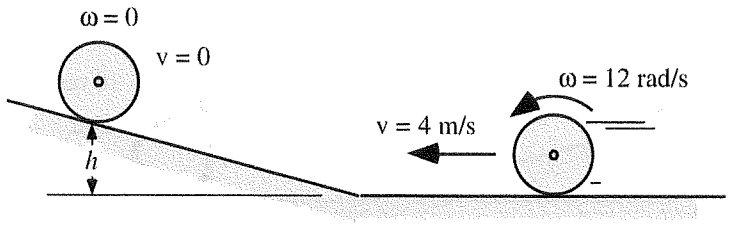
Rank the maximum height of the objects on the other side of the ramp.

						OR		
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

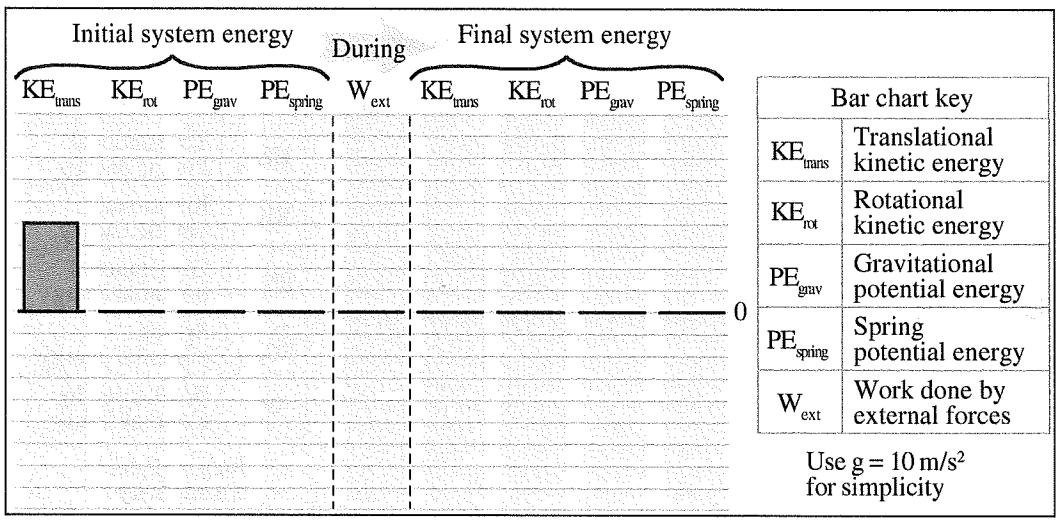
Explain your reasoning.

B6-BCT28: Solid Disk Rolling up a Ramp—Rotational Energy Bar Chart

A solid disk is initially rolling without slipping along a flat, level surface. It then rolls up an incline, coming momentarily to rest as shown.



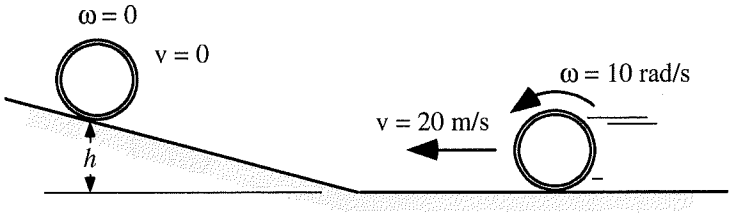
Complete the qualitative energy bar chart below for the earth-disk system for the time between when the disk is rolling on the horizontal and when it has rolled up the ramp and is momentarily at rest. Put the zero point for the gravitational potential energy at the height of the center of the hoop when it is rolling on the horizontal surface.



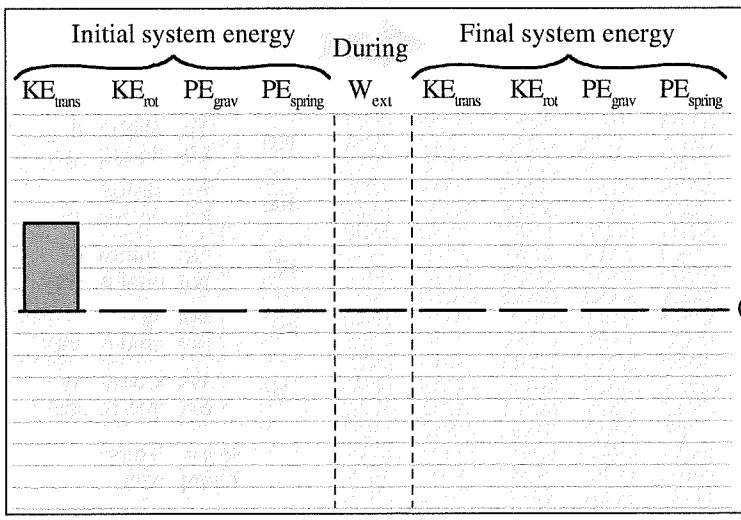
Explain your reasoning.

B6-BCT27: HOOP ROLLING UP A RAMP—ROTATIONAL ENERGY BAR CHART

A thin hoop or ring with a radius of 2 m is moving so that its center of mass is initially moving at 20 m/s while also rolling without slipping at 10 rad/s along a horizontal surface. It rolls up an incline, coming to rest as shown.



Complete the qualitative energy bar chart below for the earth-hoop system for the time between when the hoop is rolling on the horizontal surface and when it has rolled up the ramp and is momentarily at rest. Put the zero point for the gravitational potential energy at the height of the center of the hoop when it is rolling on the horizontal surface.



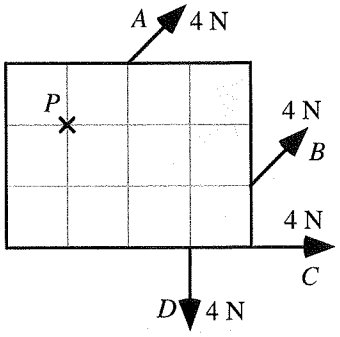
Bar chart key	
KE_{trans}	Translational kinetic energy
KE_{rot}	Rotational kinetic energy
PE_{grav}	Gravitational potential energy
PE_{spring}	Spring potential energy
W_{ext}	Work done by external forces

Use $g = 10\ m/s^2$ for simplicity

Explain your reasoning.

B6-RT25: Four Forces Acting on a Piece of Plywood—Torque

Four 4-Newton forces (*A–D*) act on a 3-m by 4-m piece of plywood as shown.



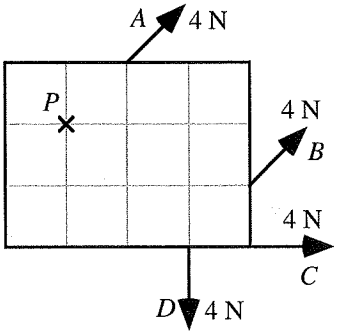
Rank the magnitudes of the torques due to the four forces about point *P*.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT26: Four Forces Acting on a Piece of Plywood—Rotation Direction

Four 4-Newton forces (*A–D*) act on a 3 m by 4 m piece of plywood that has a pivot point at *P*.

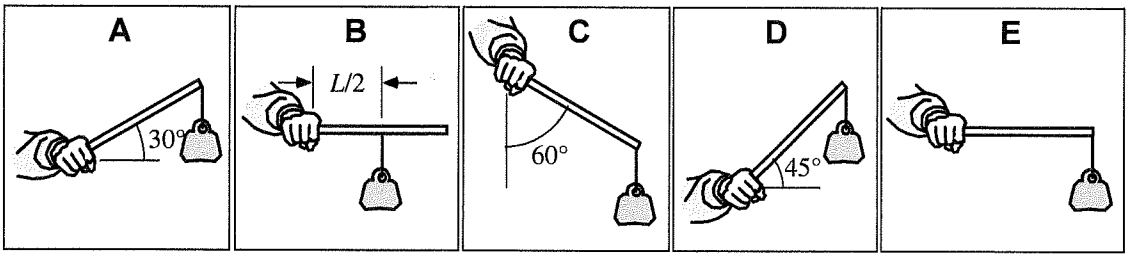


Will the plywood rotate about the pivot point *P* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *not at all*? _____

Explain your reasoning.

B6-RT23: METER STICK WITH HANGING MASS I—DIFFICULTY HOLDING

A student is holding a meter stick by one end. A 1,000 g mass is hung on the meter sticks. All of the meter sticks are identical, but the distance along the meter stick at which the 1,000 g mass is hung and the angles at which the student holds the meter stick vary. (Ignore the mass of the meter stick.)



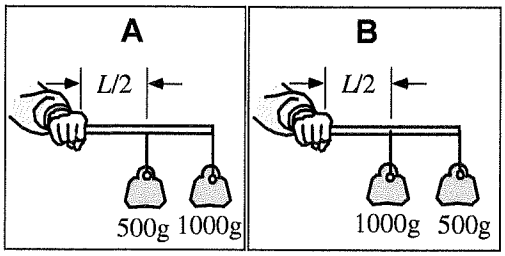
Rank the difficulty of holding the meter stick from the left end in the position shown.

					OR		
					☐	☐	☐
1 Greatest	2	3	4	5 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B6-CT24: HORIZONTAL METER STICK WITH TWO HANGING MASSES—TORQUE

In each case, a student is holding a meter stick horizontally. Each meter stick has a mass attached at the 50 cm mark and another at the 100 cm mark. The meter sticks are identical, and the specific values and locations are given in the figures.

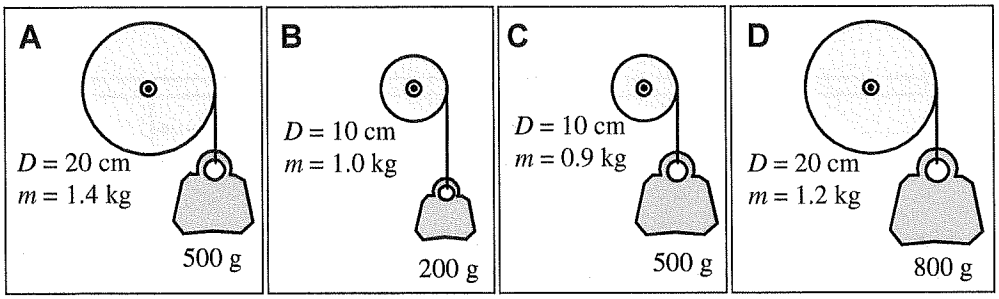


Is the magnitude of the torque by the student on the meter stick (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

B6-RT21: Hanging Weights on Fixed Disks—Torque

Vertically oriented circular disks have strings wrapped around them. The other ends of the strings are attached to hanging masses. The diameters of the disks, the masses of the disks, and the masses of the hanging masses are given. The disks are fixed and are *not* free to rotate. Specific values of the variables are given in the figures.



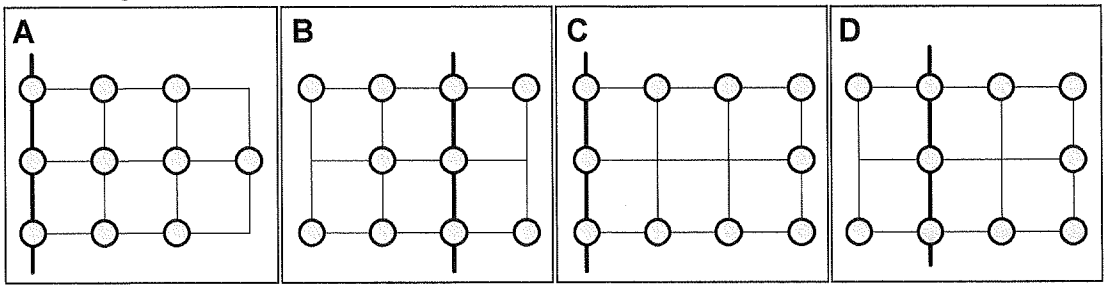
Rank the magnitudes of the torques exerted by the strings about the center of the disks.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-RT22: Systems of Point Masses—Difficult to Rotate

Each of the ten point masses in each case is identical. The solid line in each figure represents an axis about which the masses are going to be rotated. The point masses are fixed together so that they all maintain the arrangements shown while being rotated.



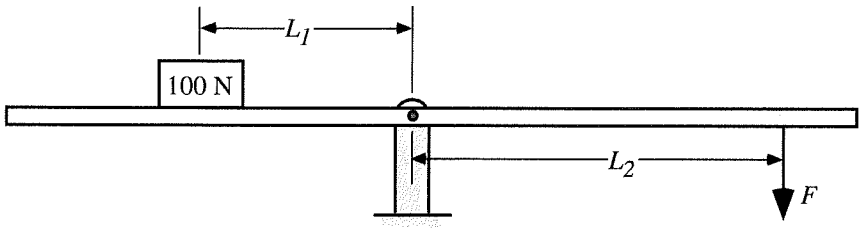
Rank these arrangements on how hard it will be to start the systems rotating.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-LMCT20: HORIZONTAL PIVOTED BOARD WITH LOAD II—FORCE TO HOLD BOARD

A 100-N weight is placed on a massless board a distance L_1 to the left of frictionless pin. A vertical downward force F is applied to the other side of the board a distance of L_2 from the pin as shown. The system is at rest.



Identify from choices (i)–(v) how each change described below will affect the magnitude of the applied force (F) on the right side of the board needed to keep the system in equilibrium.

Compared to the case above, this change will:

(i) ***increase*** the magnitude of the support force (F) on the board.
(ii) ***decrease*** the magnitude of the support force (F) on the board but not to zero.
(iii) ***decrease*** the magnitude of the support force (F) on the board **to zero**.
(iv) ***have no effect*** on the magnitude of the support force (F) on the board.
(v) *have an* ***indeterminate*** effect on the magnitude of the support force (F) on the board.

Each of these modifications is the only change to the initial situation shown in the diagram above.

(a) The 100-N weight is moved to a position closer to the pin. _____
Explain your reasoning.

(b) The support force (F) is moved to a position closer to the pin. _____
Explain your reasoning.

(c) The weight is decreased to 50 N. _____
Explain your reasoning.

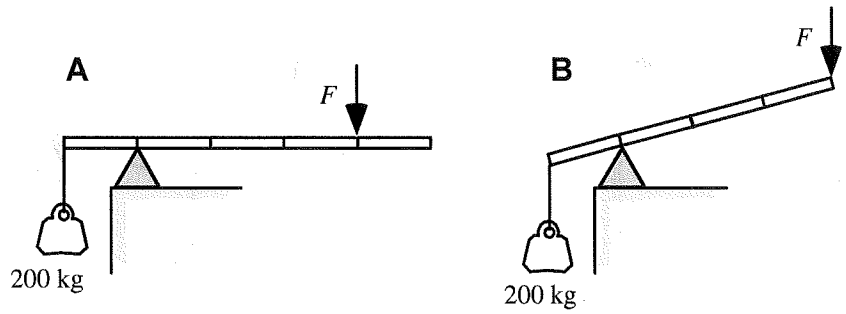
(d) The support force (F) is moved to the right end of the board. _____
Explain your reasoning.

(e) The board is made longer but the support force (F) remains at the same location. _____
Explain your reasoning.

(f) The 100-N weight and the support force (F) are both moved to positions closer to the pin. _____
Explain your reasoning.

B6-CT18: Tilted Pivoted Rods with Various Loads—Force to Hold Rods

In both cases, a massless rod is supported by a fulcrum, and a 200-kg hanging mass is suspended from the left end of the rod by a cable. A downward force F keeps the rod at rest. The rod in Case A is 50 cm long, and the rod in Case B is 40 cm long. (Each rod is marked at 10-cm intervals.)

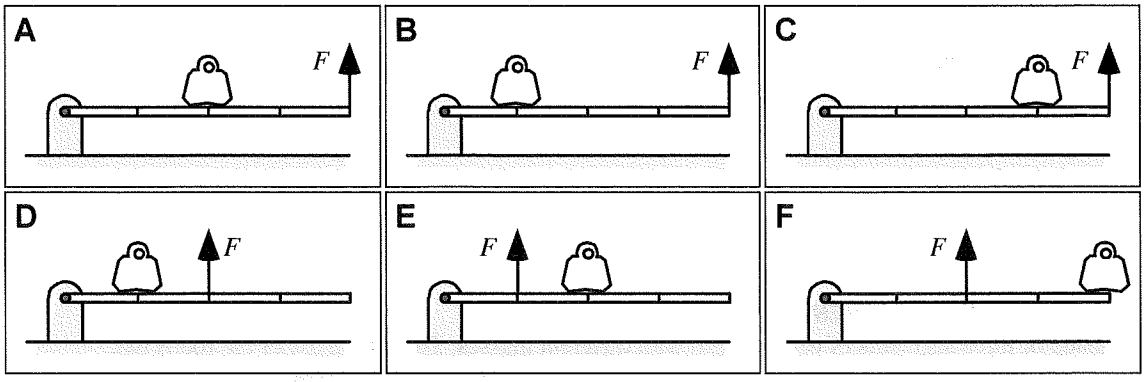


Will the magnitude of the vertical force F exerted on the rod be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

B6-RT19: Horizontal Pivoted Rods with Loads I—Force to Hold

A 2-m long massless rod supports a 12-Newton weight. The left end of each rod is held in place by a frictionless pin. In each case, a vertical force F is holding the rods and the weights at rest. The rods are marked at half-meter intervals.



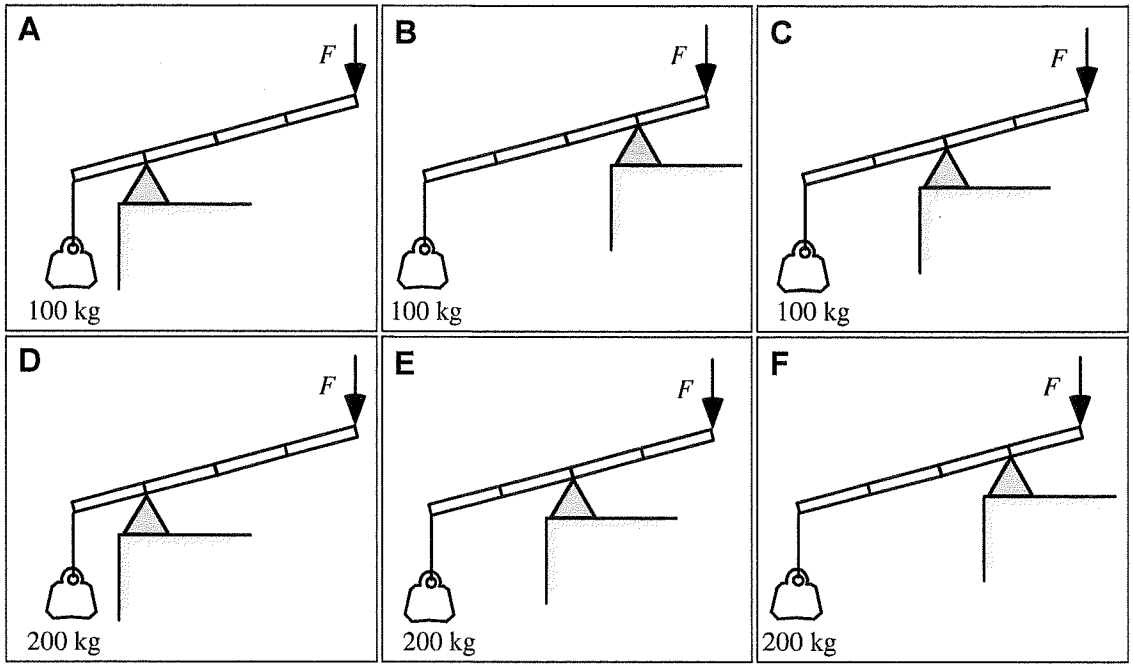
Rank the magnitude of the vertical force F applied to the rods.

						OR	
1 Greatest	2	3	4	5	6 Least	All the same	Cannot determine

Explain your reasoning.

B6-RT16: TILTED PIVOTED RODS WITH VARIOUS LOADS—FORCE TO HOLD RODS

Six identical massless rods are supported by a fulcrum and are tilted at the same angle to the horizontal. A mass is suspended from the left end of the rod, and the rods are held motionless by a downward force on the right end. Each rod is marked at 1-m intervals.



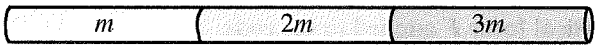
Rank the magnitude of the vertical force *F* applied to the end of the rod.

						OR		
							☐	☐
1 Greatest	2	3	4	5	6 Least		All the same	Cannot determine

Explain your reasoning.

B6-CT17: SPECIAL ROD—MOMENT OF INERTIA

A rod is made of three segments of equal length with different masses. The total mass of the rod is $6m$.

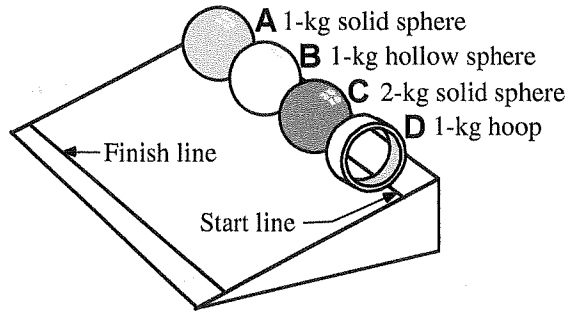


Will the moment of inertia of the rod be (i) *greater* about the left end, (ii) *greater* about the right end, or (iii) *the same* about both ends? _____

Explain your reasoning.

B6-RT14: Rolling Objects Released from Rest—Time Down Ramp

Four objects are placed in a row at the same height near the top of a ramp and are released from rest at the same time. The objects are (i) a 1-kg solid sphere; (ii) a 1-kg hollow sphere; (iii) a 2-kg solid sphere; and (iv) a 1-kg thin hoop. All four objects have the same diameter, and the hoop has a width that is one-quarter its diameter. The time it takes the objects to reach the finish line near the bottom of the ramp is recorded. The moment of inertia for an axis passing through its center of mass for a solid sphere is $\frac{2}{5}MR^2$; for a hollow sphere it is $\frac{2}{3}MR^2$; and for a hoop it is MR^2.



Rank the four objects from fastest (shortest time) down the ramp to slowest.

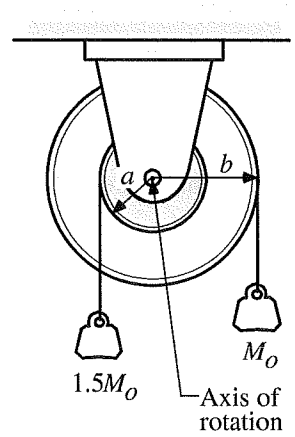
				OR	☐	☐
1 Fastest	2	3	4 Slowest		All the same	Cannot determine

Explain your reasoning.

B6-WWT15: Pulley with Hanging Weights—Angular Acceleration

Two pulleys with different radii (labeled a and b) are attached to one another so that they rotate together. Each pulley has a string wrapped around it with a weight hanging from it. The pulleys are free to rotate about a horizontal axis through the center. The radius of the larger pulley is twice the radius of the smaller one ($b = 2a$). A student describing this arrangement states:

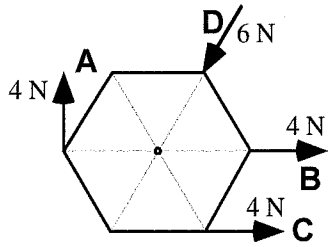
"The larger mass is going to create a counterclockwise torque and the smaller mass will create a clockwise torque. The torque for each will be the weight times the radius, and since the radius for the larger pulley is double the radius of the smaller, and the weight of the heavier mass is less than double the weight of the smaller one, the larger pulley is going to win. The net torque will be clockwise, and so the angular acceleration will be clockwise."



What, if anything, is wrong with this contention? If something is wrong, explain how to correct it. If this contention is correct, explain why.

B6-RT12: FOUR FORCES ACTING ON A HEXAGON—TORQUE ABOUT CENTER

Four forces act on a plywood hexagon as shown in the diagram. The sides of the hexagon each have a length of 1 m.



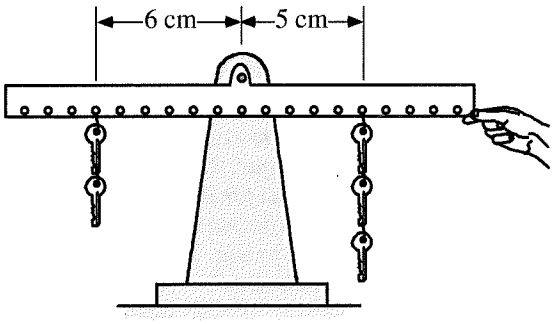
Rank the magnitude of the torque applied about the center of the hexagon by each force.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT13: BALANCE BEAM—MOTION AFTER RELEASE

Five identical keys are suspended from a balance, which is held horizontally as shown. The two keys on the left are attached to the balance 6 cm from the pivot and the three keys on the right are attached 5 cm from the pivot.

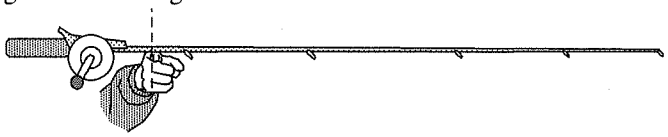


What will happen when the person lets go of the balance beam?

Explain.

B6-CT10: Fishing Rod—Weight of Two Pieces

An angler balances a fishing rod on her finger as shown.

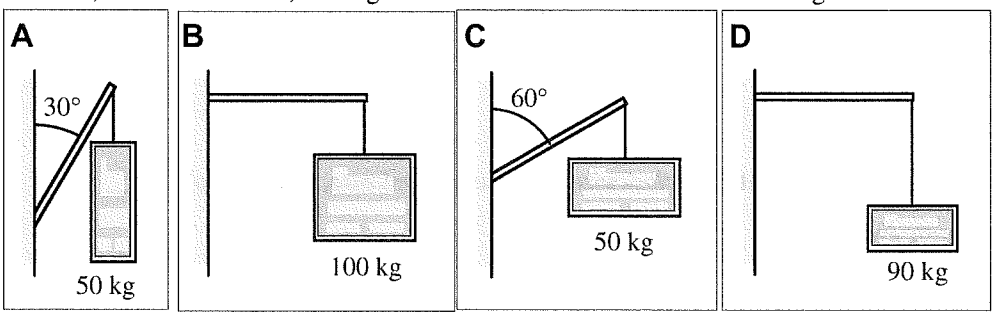


If she were to cut the rod along the dashed line, would the weight of the piece on the left-hand side be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of the piece on the right-hand side? _____

Explain your reasoning.

B6-RT11: Suspended Signs—Torque

Signs are suspended from equal-length rods on the side of a building. For each case, the mass of the sign compared to the mass of the rod is small and can be ignored. The mass of the sign is given in each figure. In Cases B and D, the rod is horizontal; in the other cases, the angle that the rod makes with the vertical is given.



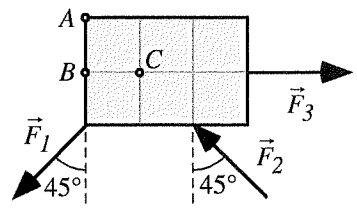
Rank the magnitude of the torque the signs exert about the point at which the rod is attached to the side of the building.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT09: THREE FORCES APPLIED TO A RECTANGLE—TORQUE DIRECTION

Three forces of equal magnitude are applied to a 3-m by 2-m rectangle. Forces $\vec{F}_1$ and $\vec{F}_2$ act at 45° angles to the vertical as shown, while $\vec{F}_3$ acts horizontally.



(a) Is the torque by $\vec{F}_1$ about point *A* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*?

_____

Explain your reasoning.

(b) Is the torque by $\vec{F}_1$ about point *B* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(c) Is the torque by $\vec{F}_1$ about point *C* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(d) Is the torque by $\vec{F}_2$ about point *A* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(e) Is the torque by $\vec{F}_2$ about point *B* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(f) Is the torque by $\vec{F}_2$ about point *C* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(g) Is the torque by $\vec{F}_3$ about point *A* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

(h) Is the torque by $\vec{F}_3$ about point *B* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

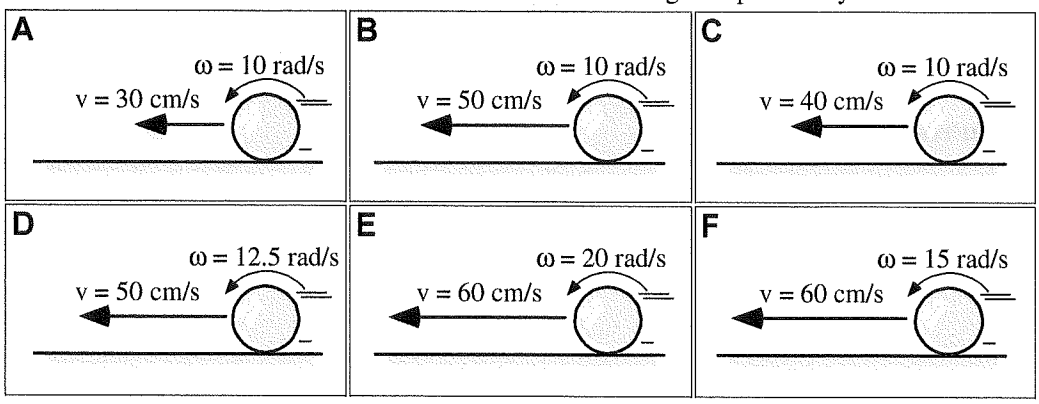
Explain your reasoning.

(i) Is the torque by $\vec{F}_3$ about point *C* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____

Explain your reasoning.

B6-RT08: Spheres Rolling—Rotational Kinetic Energy

The figures below show hollow spheres (not drawn to scale) that are rolling at a constant rate without slipping. The spheres all have the same mass, but their radii as well as their linear and angular speeds vary.



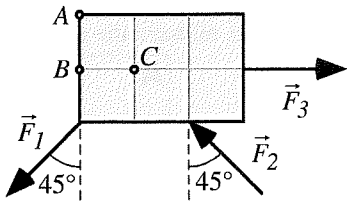
Rank the rotational kinetic energy of the spheres.

						OR	☐	☐	☐
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT07: THREE EQUAL FORCES APPLIED TO A RECTANGLE—NET TORQUE DIRECTION

Three forces of equal magnitude are applied to a 3-m by 2-m rectangle. Forces $\vec{F}_1$ and $\vec{F}_2$ act at 45° angles to the vertical as shown, while $\vec{F}_3$ acts horizontally.



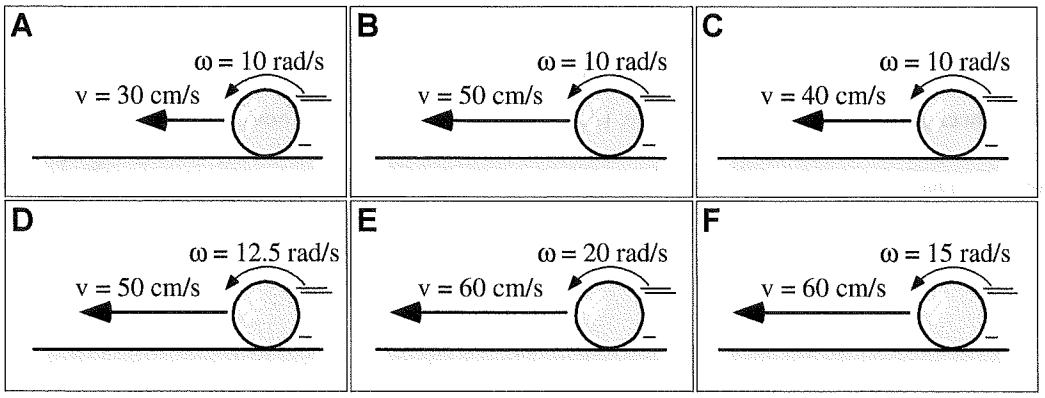
(a) Is the net torque about point *A* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____
Explain your reasoning.

(b) Is the net torque about point *B* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____
Explain your reasoning.

(c) Is the net torque about point *C* (i) *clockwise*, (ii) *counterclockwise*, or (iii) *zero*? _____
Explain how you determined your answer.

B6-RT06: Spheres Rolling—Radius

The figures below show hollow spheres (not drawn to scale) that are rolling at a constant rate without slipping. The spheres all have the same mass, but their radii as well as their linear and angular speeds vary.



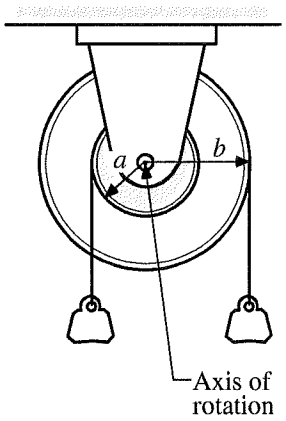
Rank the radius of the spheres.

						OR		
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B6-QRT05: PULLEYS WITH DIFFERENT RADII—ROTATION AND TORQUE

A wheel is composed of two pulleys with different radii (labeled *a* and *b*) that are attached to one another so that they rotate together. Each pulley has a string wrapped around it with a weight hanging from it as shown. The pulleys rotate about a horizontal axis at the center. When the wheel is released it is found to have an angular acceleration that is directed out of the page or counterclockwise.



(a) Is the wheel going to rotate (i) *clockwise,* (ii) *counterclockwise,* or (iii) *none*?

_____

Explain your reasoning.

(b) Is the direction of the net torque on the pulley wheels (i) *clockwise*, (ii) *counterclockwise*, or (iii) *none*? _____

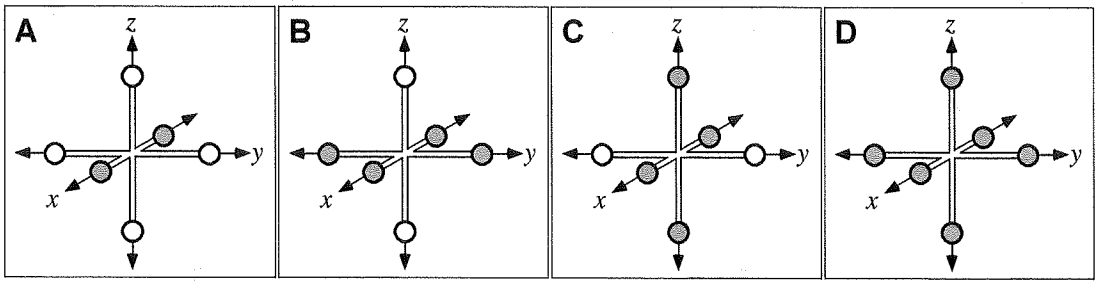
How do you know?

(c) How do the masses of the two weights compare?

Explain your reasoning.

B6-RT03: Three-Dimensional Point Objects—Moment of Inertia about the *x*-Axis

Six small brass and aluminum spheres are connected by three stiff, lightweight rods to form a rigid object shaped like a jack. The rods are joined at their centers, are mutually perpendicular, and lie along the axes of the coordinate system shown. All spheres are the same distance from the connection point of the three rods at the origin of the coordinate axis. The brass spheres are shaded in the diagram and are identical. The aluminum spheres are identical, have less mass than the brass spheres, and are unshaded in the diagram. For this problem, ignore the mass of the connecting rods.



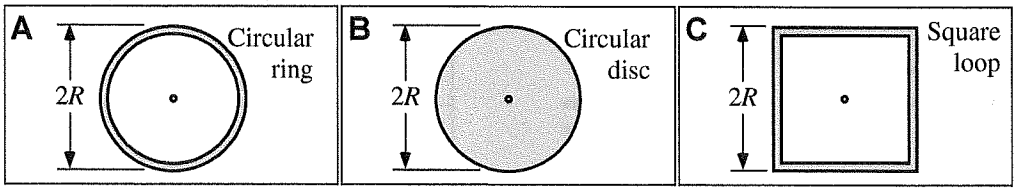
Rank the moment of inertia about the *x*-axis.

1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

B6-RT04: Flat Objects—Moment of Inertia Perpendicular to Surface

Three flat objects (circular ring, circular disc, and square loop) have the same mass M and the same outer dimension (circular objects have diameters of $2R$ and the square loop has sides of $2R$). The small circle at the center of each figure represents the axis of rotation for these objects. This axis of rotation passes through the center of mass and is perpendicular to the plane of the objects.



Rank the moment of inertia of these objects about this axis of rotation.

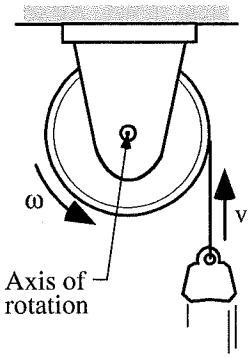
1 Greatest	2	3 Least	OR	All the same	Cannot determine

Explain your reasoning.

B6 ROTATION

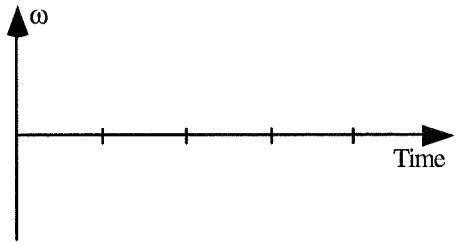
B6-CRT01: PULLEY AND WEIGHT—ANGULAR VELOCITY-TIME AND ACCELERATION-TIME GRAPHS

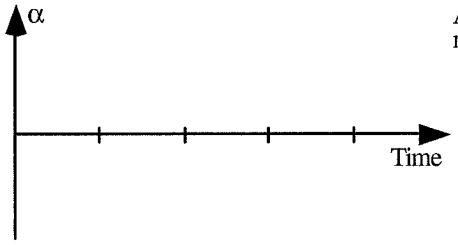
A weight is tied to a rope that is wrapped around a pulley. The pulley is initially rotating counterclockwise and is pulling the weight up. The tension in the rope creates a torque on the pulley that opposes this rotation. The weight slows down, stops momentarily, and then moves back downward.



(a) Graph of the angular velocity (ω) versus time for the period from the initial instant shown until the weight comes back down to the same height. Take the initial angular velocity as positive.

(b) Graph the angular acceleration (α) versus time for the same time period.

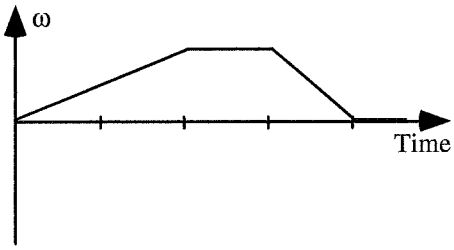


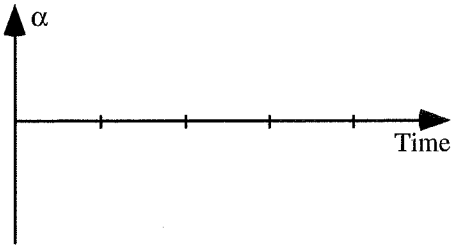


Explain your reasoning.

B6-CRT02: ANGULAR VELOCITY-TIME GRAPH—ANGULAR ACCELERATION-TIME GRAPH

Sketch an angular acceleration versus time graph given the angular velocity versus time graph shown for the same time interval.

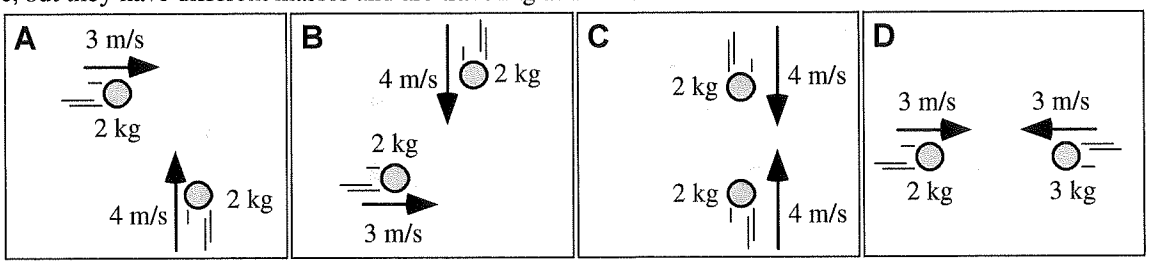




Explain your reasoning.

B5-QRT29: Colliding Ball Systems—Momentum Direction before and after Colliding

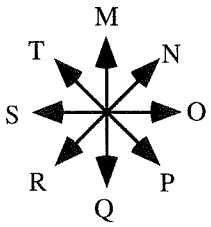
In the figures below, two balls traveling in different directions are about to collide. The balls have the same size and shape, but they have different masses and are traveling at different velocities as shown.



For the questions below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.

(a) Identify the closest directional match for the direction of the momentum of the two-ball systems before they collide.

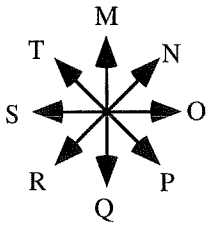
A	B
C	D



Explain your reasoning.

(b) Identify the closest directional match for the direction of the momentum of the two-ball systems after they collide if the balls stick together.

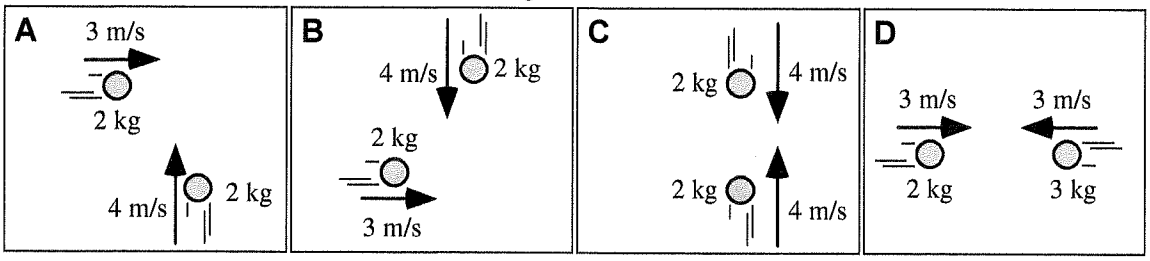
A	B
C	D



Explain your reasoning.

B5-RT28: COLLIDING BALL SYSTEMS—MOMENTUM BEFORE AND AFTER COLLIDING

In the figures below, two balls traveling in different directions are about to collide. The balls are identical in size and shape, but they have different masses and are traveling at different velocities as shown.



(a) Rank the magnitude of the momentum of the two-ball systems before they collide.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

(b) Rank the magnitude of the momentum of the two-ball systems after they collide if the balls stick together.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

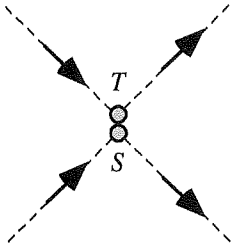
(c) Rank the magnitude of the momentum of the two-ball systems after they collide elastically (energy conserved).

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

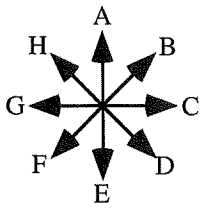
Explain your reasoning.

B5-QRT27: Colliding Steel Balls—Momentum and Impulse Direction

Two identical steel balls, *S* and *T*, are shown at the instant that they collide. The paths and velocities of the two balls before and after the collision are indicated by the dashed lines and arrows. The speeds of the balls are same before and after the collision.



For the questions below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.



(a) Which letter best represents the direction of the initial momentum of ball *T*?

_____

Explain your reasoning.

(b) Which letter best represents the direction of the final momentum of ball *T*? _____

Explain your reasoning.

(c) Which letter best represents the direction of the change in momentum for ball *T*? _____

Explain your reasoning.

(d) Which letter best represents the direction of the change in momentum for ball *S*? _____

Explain your reasoning.

(e) Which letter best represents the direction of the impulse on ball *T*? _____

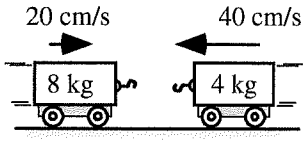
Explain your reasoning.

(f) Which letter best represents the direction of the impulse on ball *S*? _____

Explain your reasoning.

B5-SCT26: COLLIDING CARTS THAT STICK TOGETHER—FINAL KINETIC ENERGY

Two identical carts traveling in opposite directions are shown just before they collide. The carts carry different loads and are initially traveling at different speeds. The carts stick together after the collision.



Three physics students discussing this situation make the following contentions:

Alex: *"These carts will both be at rest after the collision since the initial momentum of the system is zero, and the final momentum has to be zero also."*

Belinda: *"If that were true it would mean that they would have zero kinetic energy after the collision, and that would violate conservation of energy. Since the right-hand cart has more kinetic energy, the combined carts will be moving slowly to the left after the collision."*

Chano: *"I think that after the collision the pair of carts will be traveling left at 20 cm/s. That way conservation of momentum and conservation of energy are both satisfied."*

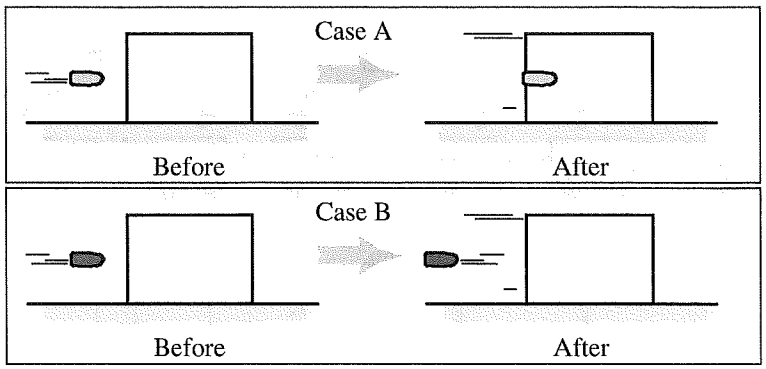
With which, if any, of these students do you agree?

Alex _____ Belinda _____ Chano _____ None of them_____

Explain your reasoning.

B5-CT25: Bullet Strikes a Wooden Block—Block and Bullet Speed After Impact

In Case A, a metal bullet penetrates a wooden block. In Case B, a rubber bullet with the same initial speed and mass bounces off of an identical wooden block.



(a) Will the speed of the wooden block after the collision be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

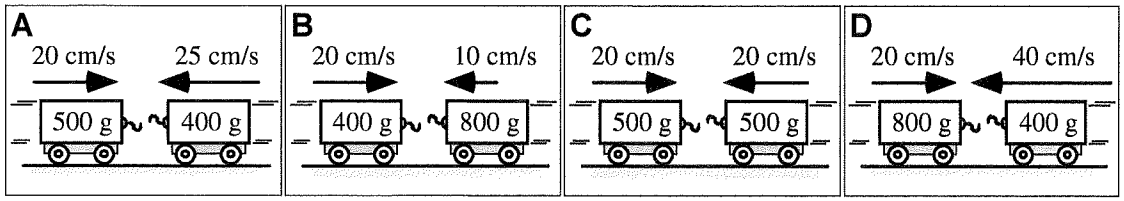
Explain your reasoning.

(b) In Case B, will the speed of the bullet after the collision be (i) *greater than*, (ii) *less than*, or (iii) *the same as* the speed of the bullet just before the collision? _____

Explain your reasoning.

B5-RT23: COLLIDING CARTS STICKING TOGETHER—FINAL SPEED

Two carts traveling in opposite directions are about to collide. The carts are all identical in size and shape, but they carry different loads and are traveling at different speeds. The carts stick together after the collision. There is no friction between the carts and the ground.



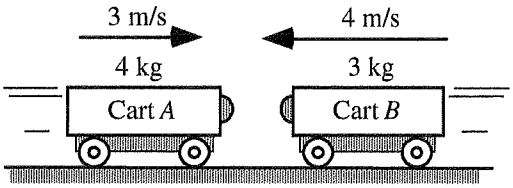
Rank the speed of the two-cart systems after the collision.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-SCT24: TWO MOVING CARTS—RESULT OF COLLISION

Carts A and B are shown just before they collide. Four students discussing this situation make the following contentions:



Alma: *"After the collision, the carts will stick together and move off to the left. Cart B has more speed, and its speed is going to determine which cart dominates in the collision."*

Baxter: *"I think they'll stick together and move off to the right because Cart A is heavier. It's like when a heavy truck hits a car: The truck is going to win no matter which one's going fastest, just because it's heavier."*

Callie: *"I think the speed and the mass compensate, and the carts are going to be at rest after the collision."*

Dante: *"The carts must have the same momentum after the collision as before the collision, and the only way this is going to happen is if they keep the same speeds. All the collision does is change their directions, so that Cart A will be moving to the left at 3 m/s and Cart B will be moving to the right at 4 m/s."*

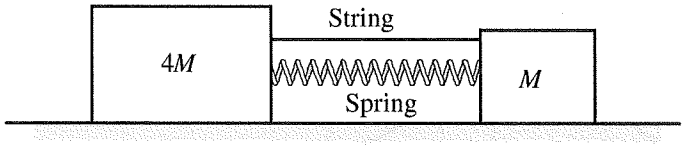
With which, if any, of these students do you agree?

Alma _____ Baxter _____ Callie _____ Dante _____ None of them_____

Explain your reasoning.

B5-CT21: Two Boxes on a Frictionless Surface—Momentum and Speed

Two boxes are tied together by a string and are sitting at rest on a frictionless surface. Between the two boxes is a massless compressed spring. The string tying the two boxes together is cut and the spring expands, pushing the boxes apart. The box on the left has four times the mass of the box on the right.



(a) After the string is cut and the boxes lose contact with the spring, will the magnitude of the momentum of the box on the left be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the momentum of the box on the right? _____

Explain your reasoning.

(b) At the instant (after the string is cut) that the boxes lose contact with the spring, will the speed of the box on the left be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the speed of the box on the right? _____

Explain your reasoning.

B5-WWT22: Ball Hitting a Wall—Momentum

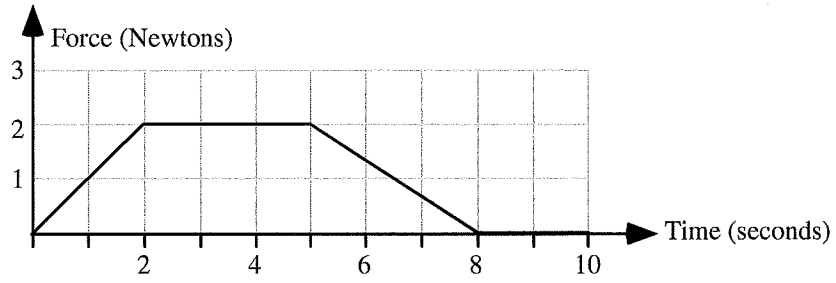
A student observing a rubber ball hitting a wall and rebounding states:

"The change in momentum for the ball is equal and opposite to the change in momentum for the wall, because in this situation momentum has to be conserved."

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

B5-WWT19: FORCE-TIME GRAPH II—IMPULSE APPLIED TO BOX

A 10-kg box, initially at rest, moves along a frictionless horizontal surface. A horizontal force to the right is applied to the box. The magnitude of the force changes as a function of time as shown.



A student calculates that the impulse applied by the force during the first 2 seconds is 4 N·s and that the impulse applied during the following 3 seconds is 6 N·s.

What, if anything, is wrong with these calculations? If something is wrong, identify it and explain how to correct it. If these calculations are correct, explain why.

B5-WWT20: TWO SKATERS PUSHING OFF EACH OTHER—FORCE

Two skaters, a large girl and a small boy, are initially standing face-to-face but then push off each other. After they are no longer touching, the boy has more kinetic energy than the girl. A physics student who is watching makes the following contention about the forces that the boy and girl exerted on each other:

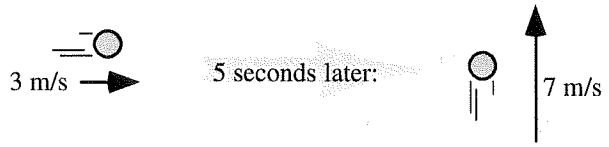
"Since the boy has more kinetic energy, he also has more momentum, so the girl had to have pushed harder on him than he pushed on her."

What, if anything, is wrong with this contention? If something is wrong, identify all problems and explain how to correct them. If this contention is correct, explain why.

B5-WWT17: Object Changing Velocity IV—Impulse

A student proposes the following description for the impulse on a 2-kg object that changes direction and speed as shown:

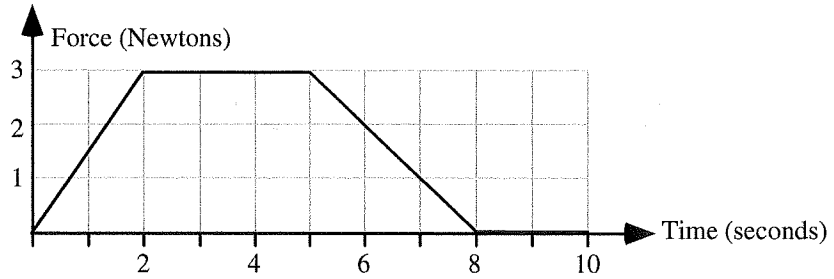
"The object goes from moving at 3 m/s in the positive x-direction to 7 m/s in the positive y-direction in 5 seconds. So the impulse given to it is 8 kg·m/s, since the impulse equals the change in momentum. The 5 seconds does not enter into the calculation of this impulse."



What, if anything, is wrong with this statement? If anything is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

B5-RT18: Force-Time Graph I—Impulse Applied to Box

A 10-kg box, initially at rest, moves along a frictionless horizontal surface. A horizontal force to the right is applied to the box. The magnitude of the force changes as a function of time as shown.



Rank the impulse applied to the box by this force during each 2-second interval indicated below.

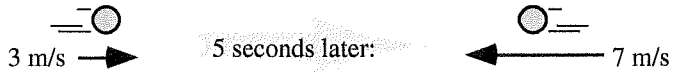
A. 0 to 2 s	B. 2 to 4 s	C. 4 to 6 s	D. 6 to 8 s	E. 8 to 10 s
☐	☐	☐	☐	☐

1 Greatest	2	3	4	5 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

B5-WWT15: OBJECT CHANGING VELOCITY II—IMPULSE

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



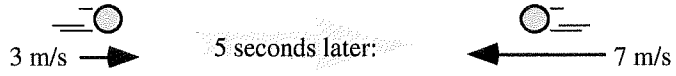
A student states:

"The change in momentum of this object during these 5 seconds was 8 kg·m/s, so the impulse applied to this object during these 5 seconds was 8/5 kg·m/s."

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct all errors. If this statement is correct, explain why.

B5-WWT16: OBJECT CHANGING VELOCITY III—IMPULSE

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



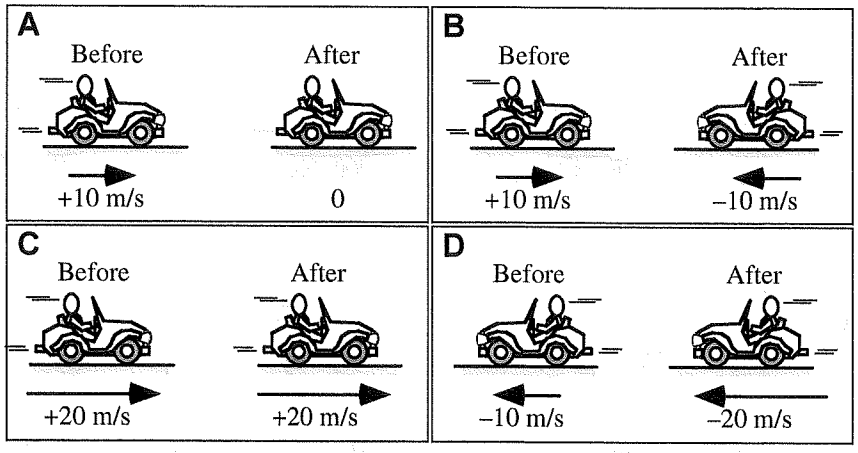
A student states:

"The change in velocity for this 2 kg object was 4 m/s, so the change in momentum, and also the impulse, was 8 kg·m/s."

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

B5-RT13: Cars—Change in Momentum During a Change of Velocity

Before and after "snapshots" of a car's velocity are shown. All cars have the same mass.



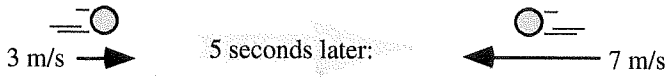
Rank the magnitude of the change in momentum of the cars.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-SCT14: Object Changing Velocity I—Impulse

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



Several students discussing the impulse on this object state the following:

Andre: *"The impulse is equal to the change in momentum, which is (2 kg)(3 m/s + 7 m/s) = 20 kg·m/s."*

Bela: *"But the change in velocity is 4 m/s. We multiply by the mass to get the change in momentum, and also the impulse, which is 8 kg·m/s."*

Carleton: *"The change in momentum of this object during these 5 seconds was 8 kg·m/s so the impulse applied to this object during these 5 seconds was 8/5 kg·m/s."*

Dylan: *"The impulse is the force F times the time t, and since we don't know the force, we can't find the impulse for this situation."*

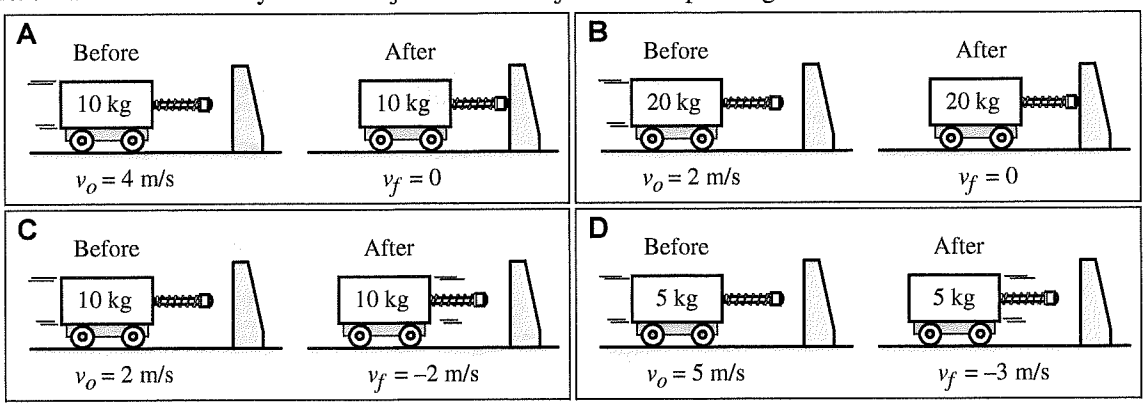
With which, if any, of these students do you agree?

Andre _____ Bela _____ Carleton _____ Dylan _____ None of them_____

Explain your reasoning.

B5-QRT12: BOUNCING CART—DIRECTION OF THE CHANGE IN MOMENTUM

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of the cart just before and just after impact is given.



(a) Is the direction of the change in momentum in Case A *to the left* or *to the right*? If the change in momentum *cannot be determined,* state that explicitly. _____
Explain your reasoning.

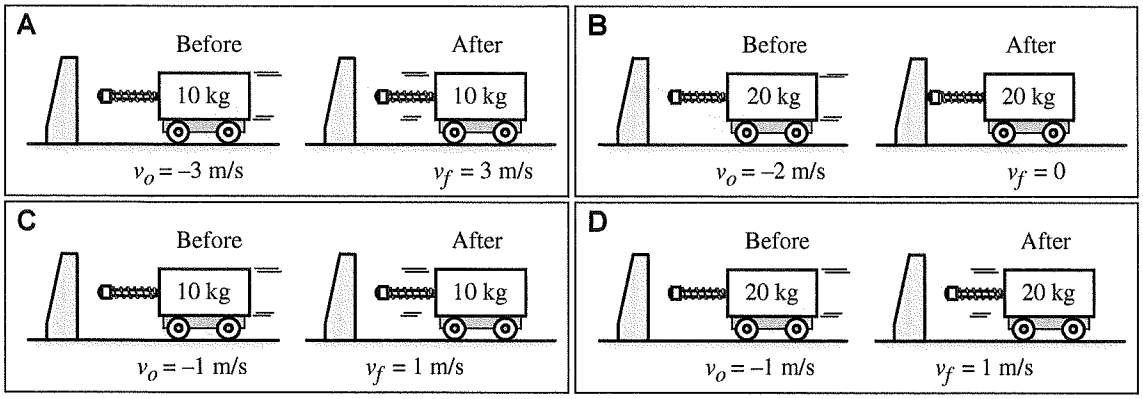
(b) Is the direction of the change in momentum in Case B *to the left* or *to the right*? If the change in momentum cannot be determined, state that explicitly. _____
Explain your reasoning.

(c) Is the direction of the change in momentum in Case C *to the left* or *to the right*? If the change in momentum *cannot be determined,* state that explicitly. _____
Explain your reasoning.

(d) Is the direction of the change in momentum in Case D *to the left* or *to the right?* If the change in momentum *cannot be determined,* state that explicitly. _____
Explain your reasoning.

B5-RT11: Bouncing Cart II—Change in Momentum

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of each cart just before and just after impact is given.



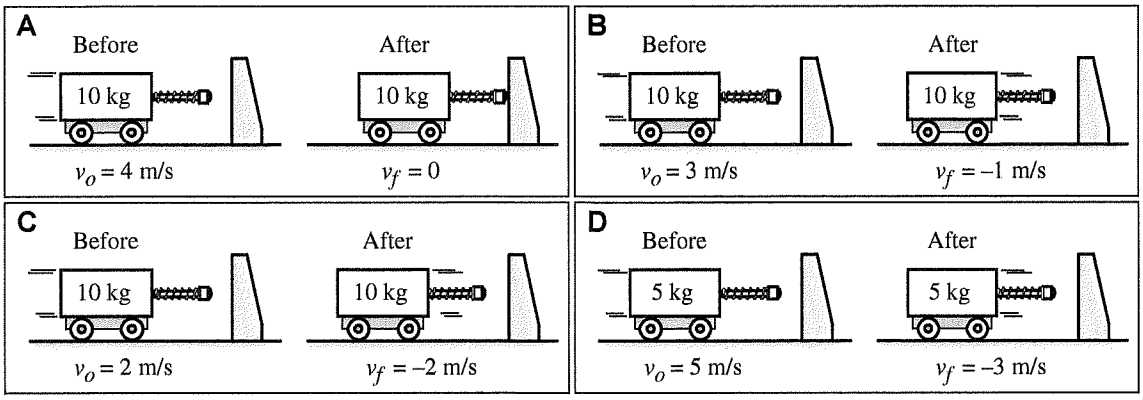
Rank the magnitude of the change in momentum of the carts.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-RT10: BOUNCING CART I—CHANGE IN MOMENTUM

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of the cart just before and just after impact is given.



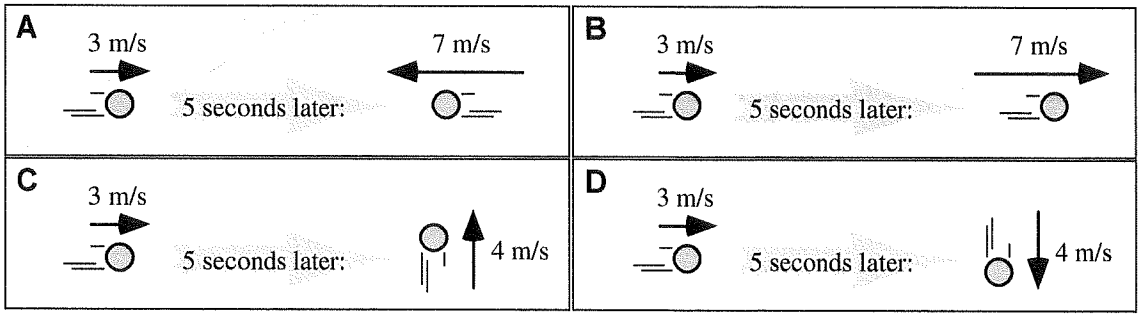
Rank the magnitude of the change in momentum of these carts.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-QRT09: Object Changing Velocity—Direction of the Impulse

An object changes its velocity as forces act on it for 5 seconds in various ways shown below.

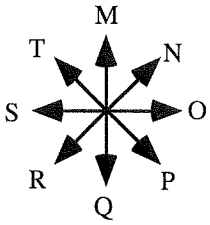


For the question below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.

(a) Identify the closest directional match for the direction of the impulse on the ball for these cases.

Explain your reasoning.

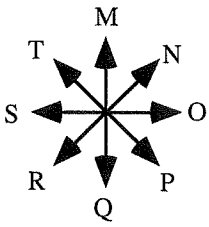
A	B
C	D



(b) Identify the closest directional match for the direction of the change in the momentum for the ball for these cases.

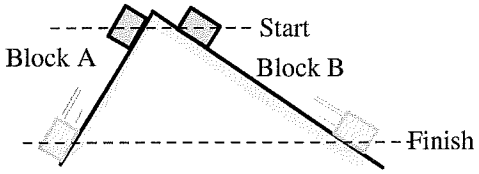
Explain your reasoning.

A	B
C	D



B5-QRT07: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK AND MOMENTUM

Two blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Block B weighs more than Block A.



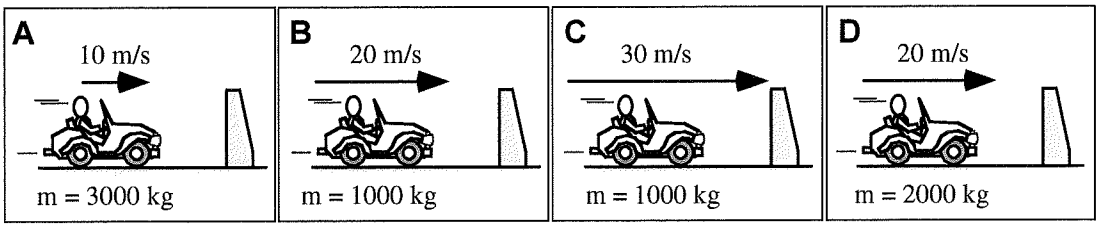
(a) Is the work done by the gravitational force on Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done by the gravitational force on Block B? _____
Explain your reasoning.

(b) Is the speed of Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the speed of Block B? _____
Explain your reasoning.

(c) Is the momentum of Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the momentum of Block B? _____
Explain your reasoning.

B5-RT08: CARS STOPPED BY CONSTANT FORCE BARRIERS—STOPPING TIME

Cars moving along horizontal roads are about to be stopped when they hit a protective barrier. All of the cars are the same size and shape, but they are moving at different speeds and have different masses. The barriers are all identical and exert the same constant force.



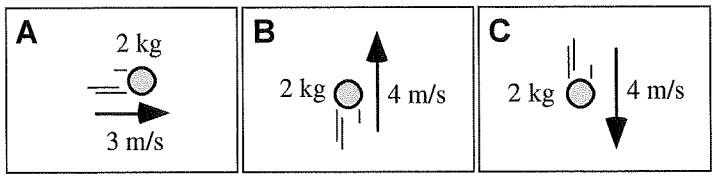
Rank the time that it takes to stop the cars as the barriers apply the same constant force.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-RT06: Moving Ball II—Momentum and Kinetic Energy

In the figures below, balls are traveling in different directions. The balls have the same size, mass and shape, but they are traveling with different velocities as shown.



(a) Rank the magnitude of the momentum of the balls.

☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

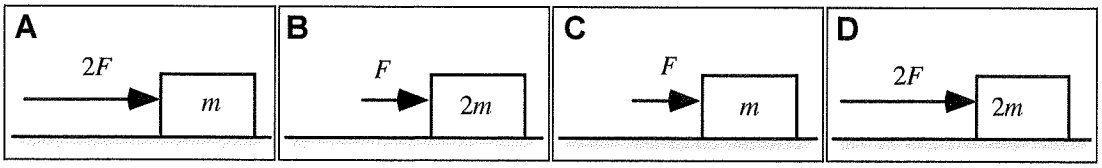
(b) Rank the kinetic energy of the balls.

☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-RT04: FORCE PUSHING BOX III—CHANGE IN MOMENTUM

Identical boxes that are filled with different amounts of sand are initially at rest. A horizontal force is applied, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force is applied are given in each figure.



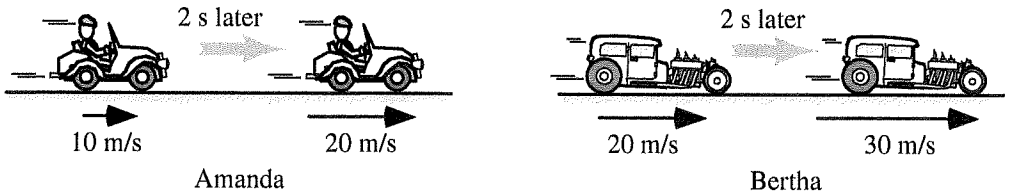
Rank the magnitude of the change in momentum for each box for the same time interval.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

B5-QRT05: AMANDA AND BERTHA'S CAR RACE—WORK AND IMPULSE

Amanda and Bertha are driving cars in a race. Their two cars, including Amanda and Bertha, have the same mass. At one point in the race, they both change their speeds by 10 m/s in 2 seconds. Ignore air friction.



(a) Is the work done on Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done on Bertha's car while speeding up? _____

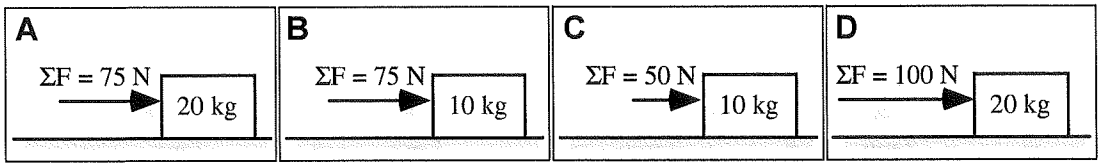
Explain your reasoning.

(b) Is the impulse on Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done on Bertha's car does while speeding up? _____

Explain your reasoning.

B5-RT02: Force Pushing Box I—Change in Momentum

Identical boxes that are filled with different objects are initially at rest. A horizontal force is applied for 10 seconds, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force are applied is given in each figure.



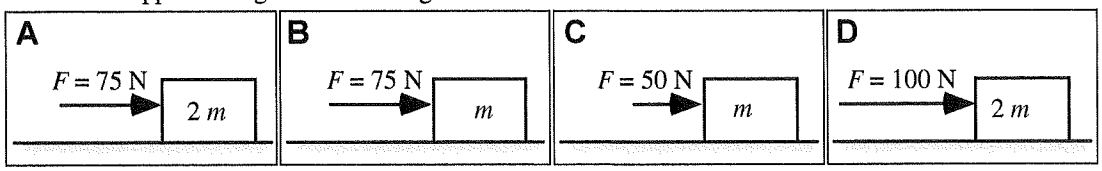
Rank the magnitude of the change in momentum during a 10-second interval for each box.

				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B5-RT03: Force Pushing Box II—Impulse

Identical boxes that are filled with different amounts of sand are initially at rest. A horizontal force is applied, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force is applied are given in each figure.



Rank the magnitude of the impulse on each box for a 2-second time interval.

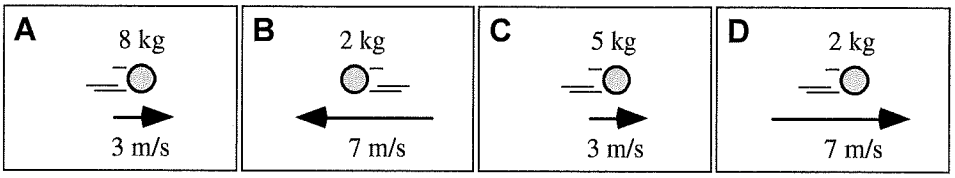
				OR		
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

B5 MOMENTUM AND IMPULSE

B5-RT01: MOVING BALL I—MOMENTUM AND KINETIC ENERGY

In the figures below, balls are traveling in different directions. The balls have the same size and shape, but they have different masses and are traveling at different velocities as shown.



(a) Rank the magnitude of the momentum of the balls.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

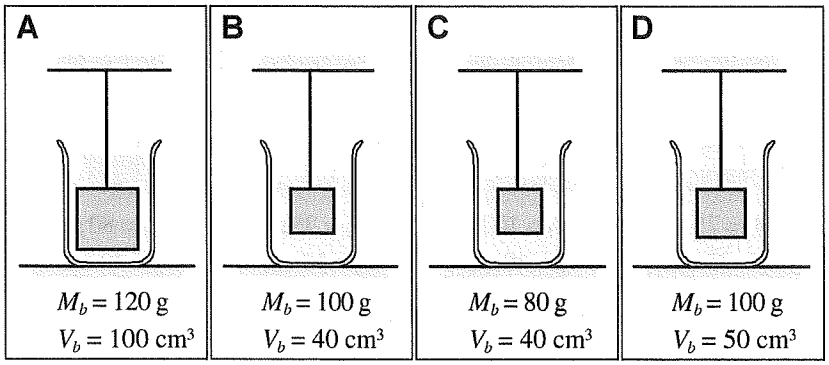
(b) Rank the kinetic energy of the balls.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT05: BLOCKS SUSPENDED IN LIQUIDS—BUOYANT FORCE

In each case, a block hanging from a string is suspended in a liquid. The blocks are made of different materials and vary in mass and volume as shown. All of the containers have the same volume of an identical liquid.



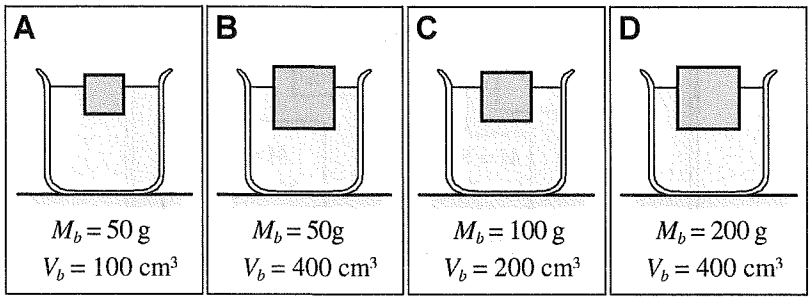
Rank the buoyant force exerted by the liquid on the blocks.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT06: BLOCKS FLOATING IN LIQUIDS—BUOYANT FORCE

In each case, a block floats in a liquid. The blocks are made of different materials and vary in mass and volume as shown. All of the containers have the same volume of an identical liquid.



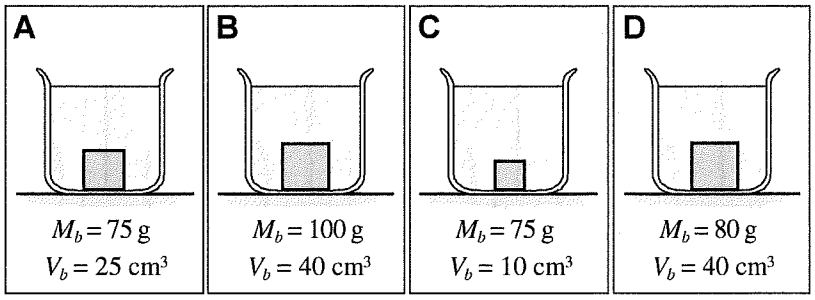
Rank the buoyant force exerted by the liquid on the blocks.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT07: Blocks at the Bottom of Liquids—Buoyant Force

In each case, a block is at rest at the bottom of a beaker filled with liquid. The blocks are made of different materials and vary in mass and volume, as shown. The liquid is the same in each beaker, and the liquid levels after the blocks are added are the same for all four beakers.



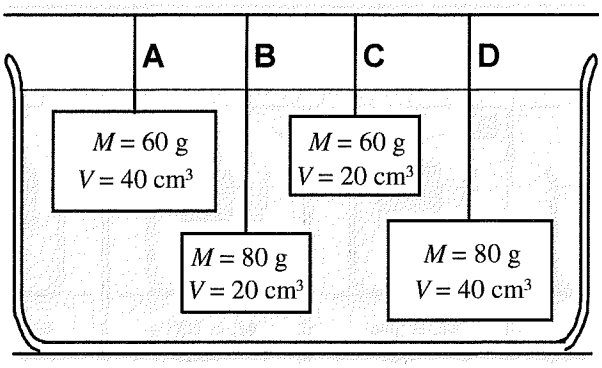
Rank the buoyant force exerted by the liquid on the blocks.

☐	☐	☐	☐	OR ☐	☐	☐
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT08: Four Metal Cubes Suspended in Liquids—Tension

Four blocks are suspended from strings in water. Cubes A and C are at the same depth, as are B and D.



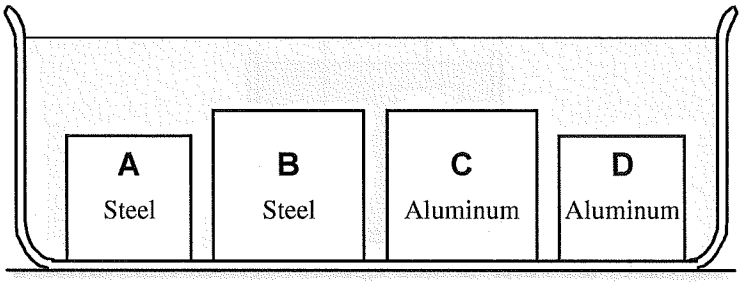
Rank the tensions in the strings.

☐	☐	☐	☐	OR ☐	☐	☐
1 Greatest	2	3	4 Least	All the same	All zero	Cannot determine

Explain your reasoning.

C2-RT09: FOUR SUBMERGED CUBES—BUOYANT FORCE

Shown are small cubes that are 10 cm on a side and larger ones that are 12 cm on a side that are submerged in water. Cubes A and B are made of steel ($\rho = 7$ g/cm^3) and cubes C and D are made of aluminum ($\rho = 2.7$ g/cm^3).



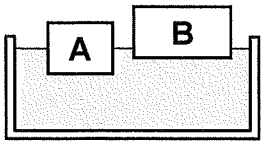
Rank the buoyant force exerted on the cubes by the water.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

C2-CT10: TWO FLOATING BLOCKS—BUOYANT FORCE

Two blocks with the same weight but different dimensions are floating in water at different levels. Block A is as tall as block B but is smaller in both other dimensions.

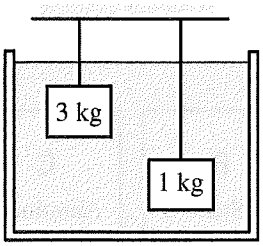


Is the buoyant force exerted by the water on block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on block B? _____

Explain your reasoning.

C2-CT11: Two Submerged Cubes—Buoyant Force, Tension, and Pressure

Two equal-sized cubes that have different masses are held by strings so that they are submerged in water at different depths.



(a) Is the buoyant force exerted by the water on the 3 kg cube (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on the 1 kg cube? _____

Explain your reasoning.

(b) Is the tension in the sting holding the 3 kg cube (i) *greater than*, (ii) *less than*, or (iii) *equal to* the tension in the string holding the 1 kg cube? _____

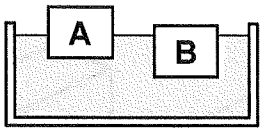
Explain your reasoning.

(c) Is the pressure exerted on the bottom surface of the 3 kg cube by the water (i) *greater than*, (ii) *less than*, or (iii) *equal to* the pressure on the bottom surface of the 1 kg cube? _____

Explain your reasoning.

C2-CT12: FLOATING CUBES—BUOYANT FORCE AND PRESSURE

Two equal-sized cubes are floating in water at different levels.



(a) Is the buoyant force exerted by the water on block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on block B? _____
Explain your reasoning.

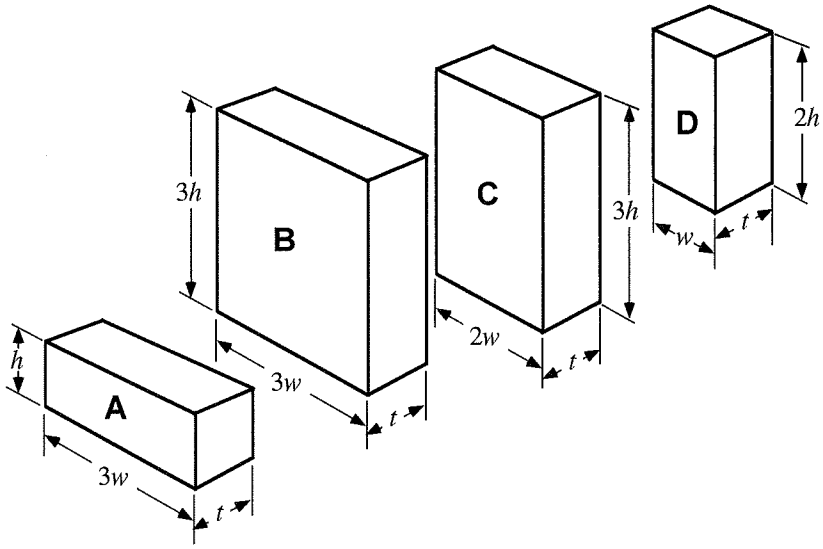
(b) Is the weight of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of block B? _____
Explain your reasoning.

(c) Is the pressure exerted on the bottom surface of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the pressure on the bottom surface of block B? _____
Explain your reasoning.

(d) Is the density of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the density of block B? _____
Explain your reasoning.

C2-RT13: Four Rectangular Blocks—Pressure

Four rectangular blocks are made of the same material, with dimensions as shown.



(a) Rank the mass of each block.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

(b) The blocks are placed as shown onto a table. Rank the pressure exerted by the blocks on the table.

				OR			
					☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.